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EDITORIAL

An Interesting Electromagnetic Problem

WE have referred on several occasions to the succession of electromagnetic conundrums which have been appearing in the correspondence columns of the American journal *Electrical Engineering*. In the May number the following interesting problem was propounded by Professor E. G. Culwick. In Fig. 1 Q represents a charge moving as shown with a velocity v past a stationary circuit C. The moving charge produces a magnetic field which can be calculated at any point by replacing the moving charge by a current element Ids, where $Ids = Qv$, and applying the Biot-Savart law. The magnetic flux through the ring C could be calculated for each position of Q; it will evidently increase as the charge approaches and decrease as it recedes. An e.m.f. will therefore be induced in C in one direction as Q approaches and in the reverse direction as it recedes, passing through zero at the moment when Q is nearest to C. In the Editorial of March 1944 we showed how the magnetic field of such a moving charge can be regarded as the result of a toroidal distribution of displacement currents in the space around the charge.

If now the charge Q is at rest and the coil C is moving to the left with the velocity v, the relative motion is the same as before and the result must therefore be the same; it is, in fact, the same phenomenon but described by two observers, one at rest with regard to C and the other at rest with regard to Q. Although the result must be the same, the explanations may be very different. If the charge Q is at rest, the coil C is merely moving through an electrostatic field, and at first sight one might say that there can be no induced electromotive force, but, although the charge Q is at rest, there are charges which are not at rest and which cannot be neglected. As the coil approaches Q the part of the coil nearest to Q will become charged negatively and the more remote part positively, assuming Q to be positive.

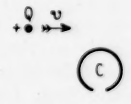

Fig. 1.

Fig. 2.

At the moment of nearest approach the conditions will be as shown in Fig. 2, and the moving charges will produce a magnetic field through the ring in the same direction as in Fig. 1; viz., downwards into the paper. As before, this magnetic flux will increase as the coil approaches Q and decrease as it recedes. Although the calculation of the

charge distribution and the application of the Biot-Savart formula would enormously complicate the determination of the induced electromotive force as compared with the case when the coil is at rest and the charge moving, there can be no doubt that the result would be the same. If one imagines a voltmeter connected between the open ends of C, the reading on it would be the same in both cases. In many problems involving the relative motion of conductors and magnetic fields, of the two alternative assumptions, one gives a simple solution and the other a very complicated one.

It may be objected that Fig. 1 has been unduly simplified by omitting the electrostatic charges induced on the ring. It is, of course, true that the same charges will be induced on the ring in both cases, but as the ring in Fig. 1 is at rest the charges will be purely electrostatic and will have no effect on the magnetic field, which is produced entirely by the moving charge Q.

G. W. O. H.

TRANSMISSION-LINE CALCULATIONS*

Use of Impedance Circle Diagrams

By W. C. Vaughan, M.B.E., B.Sc., Ph.D., A.M.I.E.E.

ALTHOUGH Circle Diagrams have been widely used during recent years for the solution of transmission-line problems, it has been the writer's experience that many radio engineers are unfamiliar with the derivation of these valuable constructions. There appears to be a widespread tendency to use these devices as means of obtaining ready-made solutions by purely rule-of-thumb operations. In the same way that the user of a slide rule who is not familiar with its basic theory may gain facility without appreciating the range of versatility of the instrument, so the possibilities of applying Circle-Diagram technique to new problems cannot be fully realized unless one has, at least, some knowledge of the derivation of the constructions employed. Comprehensive accounts of the Cartesian and polar forms of the Impedance-Circle Diagram have been given by Willis Jackson and G. H. Huxley[1], but it is believed that these expositions may not be simple enough to appeal to the engineer possessing limited mathematical ability or experience. The following treatment, therefore, aims at providing, for those whose needs do not go much beyond the practical, a simplified approach and an indication of proofs of construction which require little more than a knowledge of elementary geometry.

Fundamentally, the Impedance-Circle Diagram provides solutions to the problem of determining the input impedance of a transmission line of known constants and specified length when it is terminated by a given complex impedance. The well-known relation,

$$Z'_i = Z_0 \frac{Z'_t + Z_0 \tanh Pl}{Z_0 + Z'_t \tanh Pl} \quad \ldots \quad \ldots \quad (1)$$

which gives in complex ohms Z'_i, the input impedance of a length l of a line of surge impedance Z_0 and propagation constant P when terminated in any load impedance Z'_t complex ohms, forms the basis of most transmission line calculations.† It is by no means evident that this relation can be translated into graphical form which will permit ready solution of a variety of problems which are apt to be encountered. Furthermore, textbooks rarely emphasize the fact that any complex impedance Z'_t may be regarded as equivalent to a length δ of

* MS accepted by the Editor, October 1946.

[1] Willis Jackson and G. H. Huxley, *J. Instn elect. Engrs*, 1944, Part III, Vol. 91, pp. 105–116.

† For most practical purposes in radio engineering, Z_0 may be regarded as purely resistive and it is then convenient to express Z'_i and Z'_t in terms of this quantity. This may be done by rewriting equation (1) as

$$\frac{Z'_i}{Z_0} = \frac{\frac{Z'_t}{Z_0} + \tanh Pl}{1 + \frac{Z'_t}{Z_0} \tanh Pl}$$

or $$Z_i = \frac{Z_t + \tanh Pl}{1 + Z_t \tanh Pl}$$

in which $Z_i = \frac{Z'_i}{Z_0}$ and $Z_t = \frac{Z'_t}{Z_0}$. The unprimed symbols Z_i and Z_t now represent the input and terminating impedances expressed in terms of Z_0 as unit and are known as the " normalized " values of Z'_i and Z'_t.

transmission line of known characteristics terminated in a purely resistive load R'_t, although this concept has a great deal to commend it when the impedance in question forms the termination of a transmission line. Thus, as indicated in Fig. 1, the input

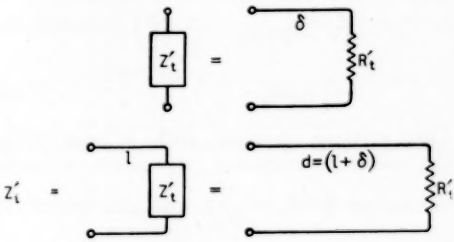

Fig. 1. *As shown, an impedance can be represented by a line terminated by a resistance.*

impedance Z'_i of a length l of line terminated in any impedance Z'_t will be identical with that of a line of similar characteristics and length $d = (l + \delta)$ terminated in a resistance R'_t. Before this conception can be of any practical significance however, it is necessary to ascertain the length δ of line of surge impedance Z_0 and propagation constant P and the resistance which must be used as its terminating load to give an input impedance equal to Z'_t. From equation (1) it is apparent that,

$$Z'_t = Z_0 \frac{R'_t + Z_0 \tanh P\delta}{Z_0 + R'_t \tanh P\delta}$$

so that,

$$\frac{Z'_t}{Z_0} = \frac{\frac{R'_t}{Z_0} + \tanh P\delta}{1 + \frac{R'_t}{Z_0}\tanh P\delta} \qquad .. \quad .. \quad (2)$$

In general, the propagation constant P is a complex quantity $\left(\alpha + j\frac{2\pi}{\lambda}\right)$ in which α is the attenuation constant and λ is the length of the wave propagated down the line. In most cases with which the radio engineer is concerned, α is small and the surge impedance Z_0 may be regarded as a pure resistance. Under these circumstances $\frac{R'_t}{Z_0}$ is, of course, a pure number and may be replaced by $\tanh \kappa$. The impedance Z'_t may be represented by $(r' + jx')$ so that (2) becomes,

$$\frac{Z'_t}{Z_0} = \frac{1}{Z_0}(r' + jx') = \frac{\tanh \kappa + \tanh P\delta}{1 + \tanh \kappa \tanh P\delta} \qquad .. \quad .. \quad (3)$$

$$= \tanh (\kappa + P\delta)$$

$$= \tanh (\kappa + j\theta)$$

$$= \frac{\sinh (\kappa + j\theta)}{\cosh (\kappa + j\theta)}$$

$$= \frac{\sinh \kappa \cos \theta + j \cosh \kappa \sin \theta}{\cosh \kappa \cos \theta + j \sinh \kappa \sin \theta}$$

$$\text{where } \theta = \frac{2\pi\delta}{\lambda}$$

If the right-hand side of this equation is now rationalized by multiplying numerator and denominator by [$\cosh \kappa \cos \theta - j \sinh \kappa \sin \theta$] the real and imaginary parts may be separated out, giving

$$\frac{r'}{Z_0} = \frac{\tanh \kappa}{\cos^2\theta + \tanh^2\kappa \sin^2\theta}$$

$$= \frac{\frac{R'_t}{Z_0}}{\cos^2\theta + \left(\frac{R'_t}{Z_0}\sin\theta\right)^2}$$

$$= \frac{\frac{R'_t}{Z_0}\left[\tan^2\theta + 1\right]}{1 + \left[\frac{R'_t}{Z_0}\tan\theta\right]^2}$$

and

$$\frac{x'}{Z_0} = \frac{\sin\theta\cos\theta\,(1 - \tanh^2\kappa)}{\cos^2\theta + \tanh^2\kappa \sin^2\theta}$$

$$= \frac{\sin\theta\cos\theta\left[1 - \left(\frac{R'_t}{Z_0}\right)^2\right]}{\cos^2\theta + \left(\frac{R'_t}{Z_0}\right)^2 \sin^2\theta}$$

$$= \frac{\left[1 - \left(\frac{R'_t}{Z_0}\right)^2\right]\tan\theta}{1 + \left[\frac{R'_t}{Z_0}\tan\theta\right]^2}$$

It is now convenient to rewrite these relations in normalized form, using Z_0 as the unit of impedance and substituting $r = \frac{r'}{Z_0}$, $x = \frac{x'}{Z_0}$ and $R_t = \frac{R'_t}{Z_0}$, so that they become

$$r = \frac{R_t(\tan^2\theta + 1)}{1 + (R_t \tan\theta)^2} \qquad .. \quad .. \quad (4)$$

and

$$x = \frac{(1 - R_t^2)\tan\theta}{1 + (R_t \tan\theta)^2} \qquad .. \quad .. \quad (5)$$

In the subsequent arguments it is important that the reader should remember that all unprimed symbols for resistance and re-

actance must be ascribed values expressed in terms of Z_0, the surge impedance of the line with which they are associated; i.e., the line is assumed to have unit surge impedance. Thus equations (4) and (5) give the components of the input impedance $(r + jx)$ of a line of length $\delta = \frac{\theta}{2\pi}\lambda$ and unit surge impedance when terminated in a resistance R_t. Considerable interest attaches itself to these relations, but whilst they readily permit the calculation of r and x when R_t and θ are known, the alternative of determining a length of line with a terminating resistance which will have a given input impedance is not an immediately obvious process. In the latter case graphical solution by means of a Circle Diagram offers the most promising method of dealing with the problem. Two forms of Circle Diagram, the first plotted in Cartesian co-ordinates and the second in polar form are commonly used and their development will now be illustrated.

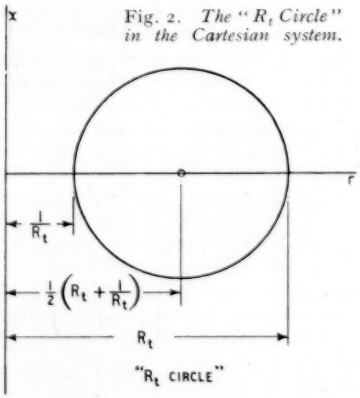

Fig. 2. *The "R_t Circle" in the Cartesian system.*

Cartesian Form

If $\tan^2\theta$ is eliminated between equations (4) and (5) a single relation connecting r, x and R_t is obtained. From (4)

$$\tan^2\theta = \frac{R_t - r}{R_t(R_t r - 1)}$$

and since from (5)

$$x^2 = \frac{(1 - R_t^2)^2 \tan^2\theta}{(1 + R_t^2 \tan^2\theta)^2}$$

it follows that,

$$x^2 = R_t r - 1 - r^2 + \frac{1}{R_t} r$$

i.e.,

$$x^2 + \left[r^2 - r\left(R_t + \frac{1}{R_t}\right)\right] = 1$$

If now a quantity $\left[\frac{1}{2}\left(R_t + \frac{1}{R_t}\right)\right]^2$ is added to both sides of this equation it becomes,

$$x^2 + \left[r - \tfrac{1}{2}\left(R_t + \frac{1}{R_t}\right)\right]^2 = \left[\tfrac{1}{2}\left(R_t - \frac{1}{R_t}\right)\right]^2 \quad \ldots \quad \ldots \quad (6)$$

This relation plotted with r and x as Cartesian co-ordinates represents a circle of radius $\frac{1}{2}\left(R_t - \frac{1}{R_t}\right)$ with its centre at $\left[r = \frac{1}{2}\left(R_t + \frac{1}{R_t}\right),\ x = 0\right]$ as shown in Fig. 2. This circle prescribes all possible values of r and x which can appear in the expression for input impedance of a line terminated in a resistance R_t. It will therefore be seen that the resistive component in this expression must lie between $\frac{1}{R_t}$ and R_t, whilst the reactive component may have a value between $\pm\frac{1}{2}\left(R_t - \frac{1}{R_t}\right)$. A series of circles of this type corresponding to different values of R_t may be constructed and these will be termed "R_t Circles." Each member of this series will have a different centre and all will cut the r axis at the appropriate values of $\frac{1}{R_t}$ and R_t.

Referring back to equations (4) and (5), a similar process can be followed to determine the relationship between r, x and $\tan\theta$ by eliminating R_t. Thus from equation (5),

$$R_t^2 = \frac{\tan\theta - x}{\tan\theta(x\tan\theta + 1)}$$

and if this is substituted in (4) the relations,

$$r^2 = \frac{R_t^2(\tan^2\theta + 1)^2}{(1 + R_t^2\tan^2\theta)^2} = x\tan\theta - x^2 + 1 - \frac{x}{\tan\theta}$$

or $r^2 + \left[x^2 - x\left(\tan\theta - \frac{1}{\tan\theta}\right)\right] = 1$

are obtained. If now the quantity $\left[\frac{1}{2}\left(\tan\theta - \frac{1}{\tan\theta}\right)\right]^2$ is added to both sides, this becomes,

$$r^2 + \left[x - \tfrac{1}{2}\left(\tan\theta - \frac{1}{\tan\theta}\right)\right]^2 = \left[\tfrac{1}{2}\left(\tan\theta + \frac{1}{\tan\theta}\right)\right]^2 \quad .. \quad (7)$$

Referred to the system of co-ordinates previously specified, this represents a circle of radius $\frac{1}{2}\left(\tan\theta + \frac{1}{\tan\theta}\right)$ with centre at $r = 0$, $x = \frac{1}{2}\left(\tan\theta - \frac{1}{\tan\theta}\right)$ as shown in Fig. 3. A family of such circles—which may be described as "θ Circles"—corresponding

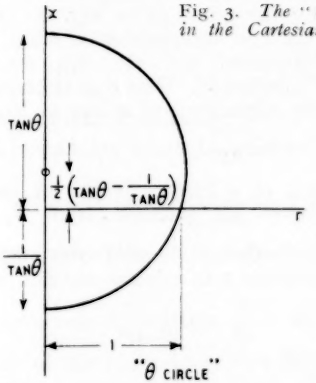

Fig. 3. *The "θ Circle" in the Cartesian system.*

to different values of θ, may now be drawn. Clearly each "θ Circle" will cut the x axis in $\tan\theta$ and $-\frac{1}{\tan\theta}$ and all will intersect the r axis at $r = 1$. Every member of this family of circles prescribes all the possible values of r and x which can appear in the input impedance expression $(r + jx)$ for a transmission line of length $\theta = \frac{2\pi\delta}{\lambda}$ when the terminating resistance is varied from zero to infinity.

If therefore, the two systems of circles are superimposed as in Fig. 4 it is apparent that the co-ordinates r and x of the intersection of any "R_t Circle" with any "θ Circle" must satisfy the two equations (4) and (5). The "R_t Circle" corresponding to, say R_{t1} passes through all values of r and x which may appear in the expression for the input impedance of a transmission line of unspecified length when it is terminated in a load resistance R_{t1}. Similarly, the "θ Circle" for a line of length θ_1 passes through all values of r and x which can feature in the input impedance expression for this length of line regardless of its terminating resistance. Thus any point which lies on both the "R_{t1} Circle" and the "θ_1 Circle" must satisfy both these requirements so that $Z_1 = (r_1 + jx_1)$ is the impedance which appears at the input of a transmission line of length θ_1 having a terminating resistance R_{t1}, where the latter are the values inscribed on the two circles which intersect at the point (r_1, x_1).

It will be observed that each "θ Circle" intersects each "R_t Circle" in two points and since both cannot represent the input impedance of the line, the nature of this ambiguity must now be examined. Referring to Fig. 4, suppose that P is any point (r, x) on a particular "R_t Circle," the diameter of which is $\left(R_t - \frac{1}{R_t}\right)$ and whose centre is at $\left[r = \tfrac{1}{2}\left(R_t + \frac{1}{R_t}\right), x = 0\right]$ and that PQ produced meets the x axis at T. It is at once clear that $ON = r$, $OQ = R_t$ and $OS = \frac{1}{R_t}$. Now since

$$\frac{ON}{OQ} = \frac{r}{R_t} = \frac{TP}{TQ} = 1 - \frac{PQ}{TQ}$$

$$= 1 - \frac{SQ\cos\psi}{\frac{OQ}{\cos\psi}}$$

$$= 1 - \frac{\left(R_t - \frac{1}{R_t}\right)}{R_t}\cos^2\psi$$

$$= 1 - \frac{\left(R_t - \frac{1}{R_t}\right)}{R_t} \cdot \frac{OQ^2}{(OQ^2 + OT^2)}$$

$$= 1 - \frac{\left(R_t - \frac{1}{R_t}\right)}{R_t} \cdot \frac{R_t^2}{(R_t^2 + OT^2)}$$

then $r = \dfrac{R_t(OT^2 + 1)}{R_t^2 + OT^2}$

from which it is obvious that if OT is made equal to $\frac{1}{\tan\theta}$ the relation shown in equation (4) is reproduced. Furthermore since,

$$x = OT\frac{NQ}{OQ}$$

$$= OT\left(1 - \frac{R_t}{r}\right)$$

$$= OT\left[\frac{(R_t^2 - 1)\tan^2\theta}{R_t^2\tan^2\theta + 1}\right]$$

the same assumption in respect of OT yields equation (5), providing x is given the negative significance which the diagram indicates. It is also clear that if SP is produced to meet the x axis in T', OT' must be the reciprocal of OT on account of the similarity of the triangles OST' and OQT. If follows that

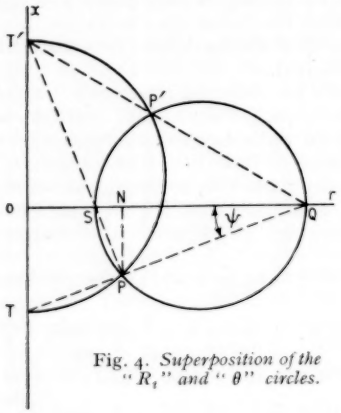

Fig. 4. *Superposition of the "R_t" and "θ" circles.*

since $T\hat{P}T'$ is a right angle, a circle can be drawn having TT' as its diameter and passing through the point P. This is, of course, the "θ Circle" cutting the x axis in $-\frac{1}{\tan\theta}$ and $\tan\theta$. Similar reasoning shows that the point P' at which QT' intersects the "R_t Circle" also lies on this "θ Circle" and it may be readily shown that,

$$r = \frac{R_t\,(OT'^2 + 1)}{R_t^2 + OT'^2}$$

and since, $OT' = \tan\theta$

$$r = \frac{R_t(\tan^2\theta + 1)}{R_t^2 + \tan^2\theta}$$

$$\text{or } r = \frac{\frac{1}{R_t}(\tan^2\theta + 1)}{\left(\frac{1}{R_t}\right)^2\tan^2\theta + 1}$$

The "R_t Circle" therefore has reciprocal properties and yields results for a termination $\frac{1}{R_t}$ as well as R_t. Attempts to make the construction serve this dual role are liable to result in confusion and it is preferable to regard points in both the first and fourth quadrants as referring to terminating resistances greater than the surge impedance of the line. Now since a resistance $\frac{1}{R_t}$ placed at the end of a line of length θ gives exactly the same input impedance as a termination R_t at the end of a line of length $\left(\theta + \frac{\pi}{4}\right)$, arcs of "$\theta$ Circles" in the first quadrant should be labelled with values of θ between 90° and 180° as shown in Fig. 5.

The method of using the Cartesian form of Circle Diagram should now be clear. Suppose that it is desired to find the input impedance of a transmission line of length l and unit surge impedance, terminated in a complex impedance $Z_t = (r_t + jx_t)$ which may be represented in the system of co-ordinates by the point P_t in Fig. 6. This point lies at the intersection of an "R_t Circle" designated by, say, R_{t1} and a "θ Circle" labelled θ_1. Thus Z_t is equivalent to the input impedance of a line of length $\delta = \frac{\theta_1}{2\pi}\cdot\lambda$ terminated in a resistance R_{t1}. The addition of a further length of line l corresponds to an increase from θ_1 to $\left(\theta_1 + \frac{2\pi l}{\lambda}\right)$ so that it is only necessary to

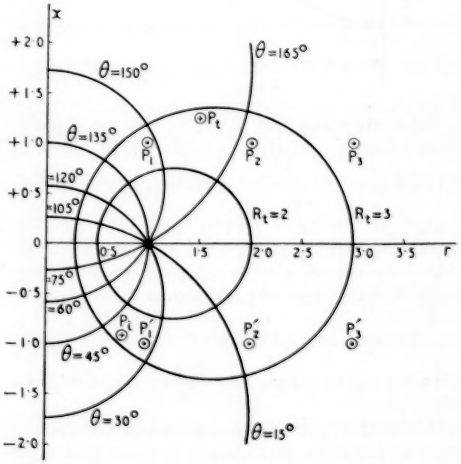

Fig. 5. *General form of the Cartesian Circle diagram.*

traverse the "R_{t1} Circle" in a clockwise direction until the point P_i at which this intersects the "θ Circle" marked with the value of $\left(\theta_1 + \frac{2\pi l}{\lambda}\right)$ is located. This intersection P_i defines the values of r_i and x_i which appear in the input expression $Z_i = (r_i + jx_i)$. It will now be appreciated that

one complete traverse of any " R_t Circle " corresponds to an increase of $\frac{\lambda}{2}$ in the length of the line.

In order to deal with problems in which the terminating resistance is a fraction of the

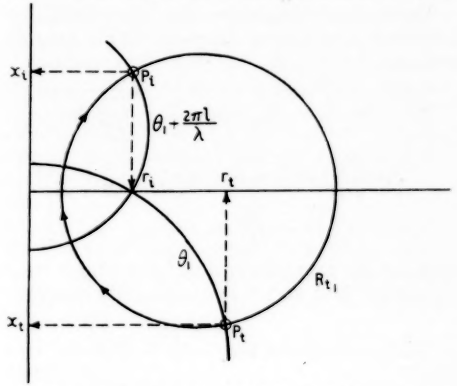

Fig. 6. *An example of the use of the Cartesian diagram.*

surge impedance of the line, it is advisable to add one-quarter of a wavelength thereby converting the fraction $\frac{1}{R_t}$ to R_t. Any problem of this nature may now be dealt with as before, and this method of treatment obviates confusion in the nomenclature of the " θ Circles." Comparison of Figs. 7(a) and 7(b) which show the variation in the components of input impedance of lines terminated in resistances $2Z_0$ and $\frac{Z_0}{2}$ respectively for different lengths of line, with the Cartesian Circle Diagram shown in Fig. 5 clearly illustrate the working of this method.

Polar Form

The equations,

$$r = \frac{R_t(1 + \tan^2\theta)}{R_t^2 \tan^2\theta + 1}$$

and

$$x = \frac{(1 - R_t^2)\tan\theta}{R_t^2 \tan^2\theta + 1}$$

may be written in the form,

$$r = \frac{2R_t}{(1 - R_t^2)\cos\phi + (1 + R_t^2)} \quad \ldots \quad (8)$$

and

$$x = \frac{(1 - R_t^2)\sin\phi}{(1 - R_t^2)\cos\phi - (1 + R_t^2)} \quad \ldots \quad (9)$$

where, $\phi = 2\theta$. Equation (8) may now be rewritten,

$$r(1 - R_t^2)\cos\phi + r(1 + R_t)^2 - 2rR_t = 2R_t$$

or

$$\frac{(1 - R_t)}{(1 + R_t)}\cos\phi = \frac{2R_t}{(1 + R_t)^2}\left(\frac{r + 1}{r}\right) - 1$$

$$= \tfrac{1}{2}\left[1 - \left(\frac{1 - R_t}{1 + R_t}\right)^2\right]\frac{r + 1}{r} - 1$$

It is now necessary to seek some method of representing the above relation in graphical form. Since interest in θ is concerned with a range of half a wavelength, graphical representation involving ϕ must cover a range of 0 to 2π for the latter variable.

If the co-ordinates (u, v) define a point in relation to a pair of axes at right angles and if this point satisfies the relations,

$$u = \frac{(1 - R_t)}{(1 + R_t)}\cos\phi \quad \ldots \quad \ldots \quad (10)$$

and

$$v = \frac{(1 - R_t)}{(1 + R_t)}\sin\phi \quad \ldots \quad \ldots \quad (11)$$

it will trace out a circle with centre at the origin and with radius $(u^2 + v^2)^{\frac{1}{2}} = \pm\left(\frac{1 - R_t}{1 + R_t}\right)$. Such a circle may again be termed an " R_t Circle " since its radius is a

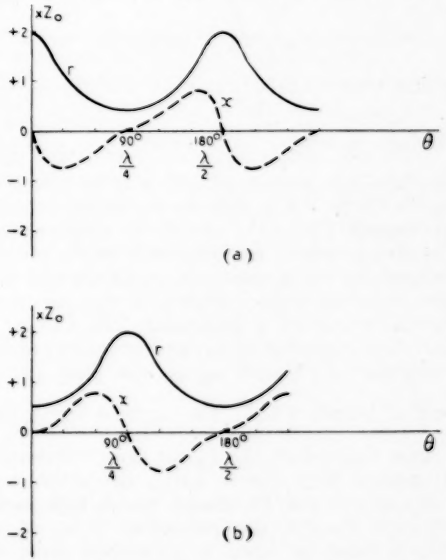

Fig. 7. *The components of input impedance of a line terminated by a resistance $2Z_0$ is shown at* (a) *and by a resistance $Z_0/2$ at* (b).

function of R_t. If the above substitutions are made in equation (8) it becomes,

$$u = \tfrac{1}{2}\left[1 - (u^2 + v^2)\right]\frac{r+1}{r} - 1$$

or

$$v^2 + u^2 + 2u\frac{r}{r+1} = 1 - \frac{2r}{r+1}$$

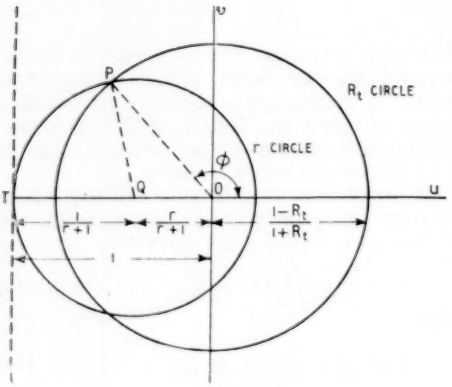

Fig. 8. *The "R_t" and "r" Circles in the polar coordinate system.*

If now a quantity $\left(\frac{r}{r+1}\right)^2$ is added to both sides of this relation it becomes,

$$v^2 + \left(u + \frac{r}{r+1}\right)^2 = \left(\frac{1}{r+1}\right)^2$$

which represents a circle of radius $\frac{1}{r+1}$ having its centre at a point $\left(0 - \frac{r}{r+1}\right)$ on the u axis. Such a circle may be termed an "r Circle." Fig. 8 shows the construction of typical R_t and r circles in relation to the axes u and v. Every point P in the plane defined by these axes can be prescribed in two separate ways. Firstly it lies on the circumference of a particular "R_t Circle" and this identifies it as representative of a resistance R_t placed across the ends of a line of length $\theta = \frac{\phi}{2}$, the angle ϕ being, of course that which the radius drawn through P makes with the u axis. Secondly, an "r Circle" can be drawn which will pass through P, and the particular value of r which must be used to construct such a circle will be that which appears in the input impedance expression for such a line. For practical purposes it is desirable to draw a number of circles corresponding to a range of values of R_t and r, so that the location of any particular point in the plane can be estimated in relation to them with accuracy. As an aid to construction it should be noted that the distance OT is equal to unity.

The second equation (9) now calls for representation in the diagram. This may be written,

$$x(1 - R_t^2)\cos\phi + x(1 + R_t)^2 - 2xR_t = (1 - R_{t^2})\sin\phi$$

i.e.,

$$\frac{(1-R_t)}{(1+R_t)}\cos\theta + 1 - \tfrac{1}{2}\left[1 - \left(\frac{1-R_t}{1+R_t}\right)^2\right] = \frac{1}{x}\frac{(1-R_t)}{(1+R_t)}\sin\theta$$

Making the transformation for u and v as in equations (10) and (11) above, this becomes,

$$u + 1 - \tfrac{1}{2}\left[1 - (u^2 + v^2)\right] = \frac{1}{x}v$$

or,

$$u^2 + 2u + 1 + v^2 - \frac{2v}{x} = 0.$$

Adding $\frac{1}{x^2}$ to each side, the relation,

$$(u+1)^2 + \left(v - \frac{1}{x}\right)^2 = \left(\frac{1}{x}\right)^2$$

is obtained. This represents a circle—which may be described as an "x Circle"—having

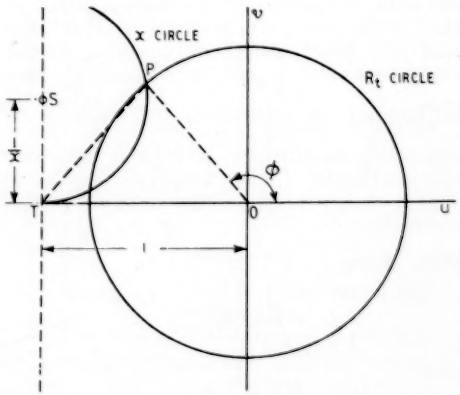

Fig. 9. *"R_t" and "x" Circles.*

a radius $\frac{1}{x}$ and centred at a point $\left(u = -1, v = \frac{1}{x}\right)$ as shown in Fig. 9. The reactance x may, of course, have either a positive or negative significance so that two sets of

circles should be constructed. Each of these will clearly pass through the point ($u = -1$, $v = 0$). Every point P in the u, v plane may now be further defined in relation to the "x Circle" and the "r Circle" which pass through it, so that any impedance $Z = (r + jx)$ may be represented by the intersection of a pair of these circles which bear the values indicated in the impedance expression. The values of R_t and ϕ which satisfy equations (8) and (9) may now be found from the "R_t Circle" which passes through this intersection and the angle which the radius through the latter makes with the u axis.

Having developed the above construction it is a simple matter to show that this satisfies the fundamental relations (8) and (9). Referring once more to Fig. 8, in the triangle QPO,

$$QP^2 = PO^2 + QO^2 - 2\,PO.\,QO\cos P\hat{O}Q$$

so that,

$$\left(\frac{1}{r+1}\right)^2 = \left(\frac{1-R_t}{1+R_t}\right)^2 + \left(\frac{r}{r+1}\right)^2 + 2\left(\frac{1-R_t}{1+R_t}\right)\left(\frac{r}{r+1}\right)\cos\phi\ ; \qquad \frac{1-r}{r+1} = \left(\frac{1-R_t}{1+R_t}\right)^2 + 2\left(\frac{1-R_t}{1+R_t}\right)\left(\frac{r}{r+1}\right)\cos\phi$$

Thus,

$$1 - \frac{1-r}{r+1} = \frac{2r}{r+1} = 1 - \left(\frac{1-R_t}{1+R_t}\right)^2 + 2\left(\frac{1-R_t}{1+R_t}\right)\left(\frac{r}{r+1}\right)\cos\phi$$

$$\frac{2r}{r+1}\left[1 - \left(\frac{1-R_t}{1+R_t}\right)\cos\phi\right] = \frac{4R_t}{(1+R_t)^2}\ ; \qquad \frac{r}{r+1} = \frac{2R_t}{(1+R_t)^2 + (1-R_t^2)\cos\phi}$$

$$1 + \frac{1}{r} = \frac{(1+R_t)^2 + (1-R_t^2)\cos\phi}{2\,R_t}$$

whence,

$$r = \frac{2R_t}{(1-R_t^2)\cos\phi + (1+R_t^2)}$$

Fig. 9 leads to the following relation,

$$TP^2 = (TO - OP\cos T\hat{O}P)^2 + (OP\sin T\hat{O}P - TP)^2$$

i.e.,

$$\left(\frac{1}{x}\right)^2 = \left[1 + \left(\frac{1-R_t}{1+R_t}\right)\cos\phi\right]^2 + \left[\left(\frac{1-R_t}{1+R_t}\right) - \frac{1}{x}\right]^2$$

Thus,

$$\frac{2}{x}\left(\frac{1-R_t}{1+R_t}\right)\sin\phi = 1 + \left(\frac{1-R_t}{1+R_t}\right)^2 + 2\left(\frac{1-R_t}{1+R_t}\right)\cos\phi$$

$$= 2\,\frac{(1+R_t^2)}{(1+R_t)^2} + 2\left(\frac{1-R_t}{1+R_t}\right)\cos\phi \qquad \frac{1}{x} = \frac{(1+R_t^2) + (1-R_t^2)\cos\phi}{(1+R_t)^2\dfrac{(1-R_t)}{(1+R_t)}\sin\phi}$$

whence,

$$x = \frac{(1-R_t^2)\sin\phi}{(1+R_t^2) + (1-R_t^2)\cos\phi}$$

The practical form of polar Circle Diagram consists of a mesh of r, x, and R_t Circles as shown in Fig. 10, although it is not unusual to replace the latter system by a suitably calibrated cursor centred at O. As in the previous case the diagram is concerned with the normalized values of r, x, and R_t. Suppose it is desired to determine the input impedance Z_i of a length of line $l = \frac{\lambda}{2}\cdot\frac{\phi_l}{2\pi}$ terminated in an impedance $Z_t = (r_t + jx_t)$. The intersection of the "r Circle" corresponding to the value r_t with the "x Circle" corresponding to x_t locates the point P_t which represents this impedance. This lies on an "R_t Circle" which gives the value of the resistance which when used as the termination of a line of length $\delta = \frac{\lambda}{2}\frac{\phi_1}{2\pi}$ will give an input impedance equal to $Z_t - \phi_1$ being, of course, the angle which OP_t makes with the u axis. If now a length of line l is added, this is equivalent to increasing the value of ϕ by an amount $\phi_l = \frac{2l}{\lambda}\cdot 2\pi$. Thus the required input impedance is represented by the point P_i located by traversing the "R_t Circle" through a further angle ϕ_l in an anticlockwise direction. In the diagram resulting from the method described, the labelling of the "R_t Circles" with terminating resistance values is unnecessary.

For the purpose of comparing the two systems which have now been described, the

ringed points in Fig. 5 are also represented in Fig. 10. It is scarcely necessary to discuss the relative merits of the Cartesian and polar forms of Circle Diagram since the user will quickly become acquainted with these after a

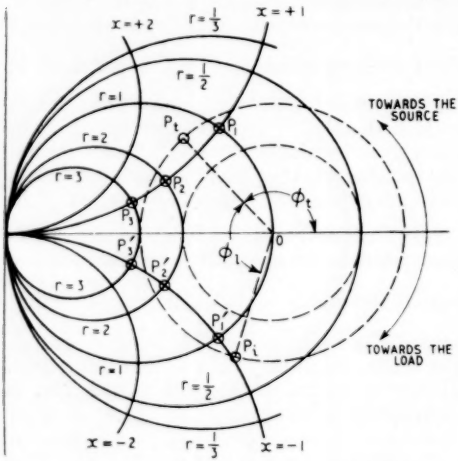

Fig. 10. *The general form of the polar Circle diagram.*

little experience. One aspect of the polar construction is, however, worthy of mention —its accuracy need not be limited by difficulties of interpolation. Furthermore it offers a method of construction suitable for solving individual problems with any desired degree of accuracy. Consider the following example as an illustration. Suppose it is desired to find the input impedance Z'_i of an 80-Ω transmission line of length $l = \frac{\lambda}{6}$ terminated in an impedance $Z'_t = [120 + 100j]$ complex ohms. In this case,

$$r_t = \frac{120}{80} = 1.5,\ x_t = \frac{100}{80} = 1.25$$

$$\theta_l = 60° \text{ or } \phi_l = 120°$$

and these values may be used to locate P_t as the point representing Z_t in both Fig. 5 and Fig. 10. Adding the specified length of line, P_i is seen to be representative of the required input impedance Z_i. The result obtained is, of course an approximation since the interpretation of the diagram depends upon interpolation.

The problem is, however, capable of more accurate solution by the following direct graphical method based on the polar construction. Construct a pair of axes TU and TV at right angles (Fig. 11) and mark a point Q_t a distance $\frac{1}{r_t + 1} = 0.4$ units along the former. Using this as centre, construct the appropriate "r Circle." Similarly, using as centre a point S_t at a distance $\frac{1}{x_T} = 0.8$ units along the vertical axis the "x Circle" may be constructed. With centre O at unit distance along TU, the R_t circle passing through the intersection P_t of the two other circles may be drawn. Making $P_t\hat{O}P_i$ equal to $\phi_l = 120°$, the point P_i on the "R_t Circle" now represents the input impedance Z_i. If Q_sS_s, a line bisecting TP_i at right angles meets the horizontal axis in Q_s and the vertical axis in S_s, then it is evident that TQ_s is equal to $\frac{1}{r_i + 1}$ and TS_s represents $\frac{1}{x_i}$. The normalized values of r_i and x_i are therefore 0.75 and $-$ 0.94 respectively. The required input impedance is accordingly $Z'_i = (60 - 75j)$ complex ohms.

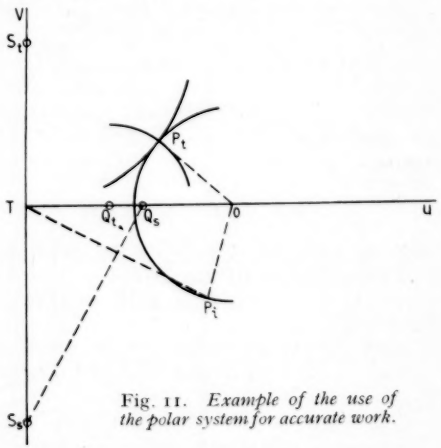

Fig. 11. *Example of the use of the polar system for accurate work.*

A similar process based on the construction of the Cartesian Circle Diagram cannot be developed, since in this case the "R_t Circles" are not concentric.

MICROWAVE COMMUNICATION LINK*

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SUMMARY.—A description is given of a single-channel duplex radio-telephone on a wavelength of 3.2 cm. A single parabolic mirror is used as aerial for both transmitted and received signals which are separated in a waveguide system. The transmitter is a klystron oscillator of about 75 mW output. The superheterodyne receiver is fitted with automatic-frequency control and automatic-gain control. Operation over optical paths up to 70 miles long is described. A signal-to-noise ratio of about 55 db is obtained over a 57-mile path.

1. Introduction

THE intensive research and development programmes carried out during the war to provide radiolocation equipment operating on centimetre wavelengths have opened up the possibility of using these wavebands to extend existing communication channels.

Magnetron and klystron valve oscillators have been designed for use in transmitters and superheterodyne receivers, and they are robust, stable and easily replaceable. The theory and practice of circuits, transmission lines, and aerials for centimetre waves are well established.

Much theoretical and experimental work has been carried out on the propagation of centimetre waves, some of which has been described[1,2]. As is to be expected, the reflection, diffraction and absorption effects of obstacles are large at these wavelengths, so that aerials must be elevated above their surroundings, and the path from transmitter to receiver should be an optical one. This does not mean that signals cannot be received over non-optical paths; indeed, under suitable meteorological conditions signals can be received over paths which are several times greater than optical. For a signal reasonably free from fluctuation, however, the optical limit should not be exceeded. For aerials placed 10 metres above the earth's surface the optical distance is 26 km and for aerials at 100 metres the distance is 82 km. It will be shown that with aerials of a reasonable size such distances can be covered with a transmitted power of less than a watt.

A recent paper[3] describes transmitting and receiving equipment, developed in 1940 as part of a programme of investigation on centimetre-wave propagation carried out for the Admiralty. In addition to its normal use for absolute measurements this equipment could also be used as a single-way radio-telephone. The results obtained showed the feasibility of such a system, and from the experience gained a duplex radio-telephone operating on a wavelength of 3.2 cm was built. This will now be described in some detail.

2. Description of Equipment

The terminal station equipment consists of a number of rack-mounted units housed in a cabinet, and an aerial system on which is mounted the r.f. duplex circuit. The duplex circuit also carries the transmitting valve, and the mixer and first i.f. stage of the receiver. The cabinet contains the following main units: (a) transmitter power supply and modulator; (b) receiver local-oscillator unit, with automatic-frequency control circuit; (c) i.f. amplifier, second detector, audio stages, and a.f.c. discriminator; (d) and (e) telephone, signalling and monitoring circuits. Front and back views of the equipment are shown in the photographs, and the layout of the panels in Fig. 1. The telephone desk set is separate from the main equipment.

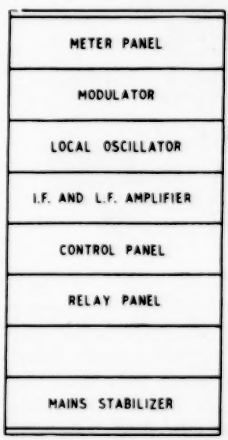

Fig. 1. *Panel layout.*

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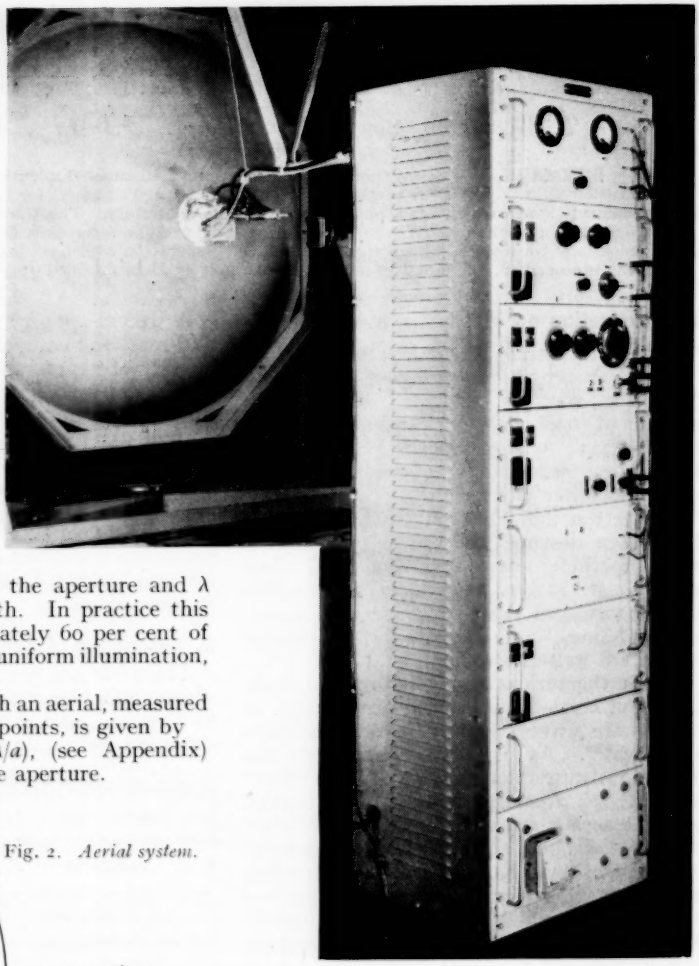
2.1. *Aerial System*

In a point-to-point radio link a high-gain aerial may be used, with a beam which is narrow in both azimuth and elevation. A paraboloid radiator fed from a dipole or waveguide is generally the most convenient form. The power gain of a circular paraboloid with reference to a Hertzian dipole is given by

$$G = \frac{8\pi}{3} \cdot \frac{A}{\lambda^2},$$

(see Appendix)



Front view of cabinet, and rear of aerial.

where A is the area of the aperture and λ the operating wavelength. In practice this is reduced to approximately 60 per cent of its value because of non-uniform illumination, giving $G' = 5A/\lambda^2$.

The beam width of such an aerial, measured between the half-power points, is given by

$2\theta = 2 \sin^{-1}(0.26\ \lambda/a)$, (see Appendix)

a being the radius of the aperture.

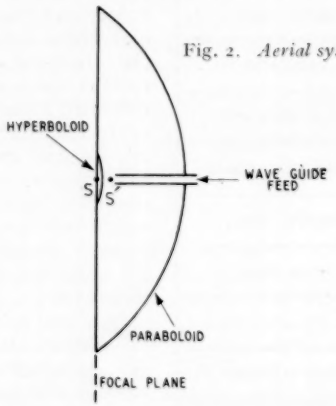


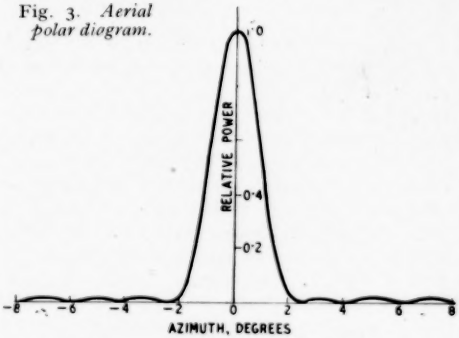
Fig. 2. *Aerial system.*

For long-distance working a paraboloid of aperture 4 ft in diameter has been used. From the above formulae this gives a gain of 5,700 (37.5 db) and a beam width of 1.6° for $\lambda = 3.2$ cm.

Fig. 2 shows the exciting system, consisting of a waveguide which projects through the mirror, and a reflecting plate in the form of a hyperboloid. From the standpoint of geometrical optics a plane wave incident on the mirror would converge at the focus S, which is in the plane of the aperture. If, however, the hyperboloid is placed with one of its foci also at S then the rays will be reflected from it and converge to a point image at S', the other focus of the hyperboloid. The practical problem is not nearly so simple, since it is a diffraction one involving dimensions comparable with the wavelength, and measurements must be

made of the shape of the wavefronts for various sizes of hyperboloid and distances from the end of the waveguide. A 6-in diameter hyperboloid of eccentricity[3] was found to give optimum results. A polar diagram of the complete system is given in Fig. 3. Its shape is the same whether the aerial is transmitting or receiving. In each case the wave in the waveguide is an H_{11} type.

Fig. 3. *Aerial polar diagram.*



In order to avoid the necessity of having different aerials for transmitting and receiving, a single mirror is used and the polarizations of the transmitted and received signals are arranged to be mutually perpendicular. A circular waveguide—which will transmit all polarizations—is therefore used to feed the mirror. Behind the mirror this waveguide separates into two branches, one carrying the received signal, whose plane of polarization (electric vector) is parallel to the plane of the branch, and the other the transmitted signal, with polarization perpendicular to it.

A diaphragm of the shape shown in Fig. 4, placed in a waveguide, can transmit an H_{11} wave polarized with its diametral electric vector perpendicular to the long dimension of the slot. There is little reflection if the dimensions of the slot are correctly chosen. This "polarization filter" will reflect waves polarized parallel to the slot. Such a filter is placed in each limb of the branch as shown in section in Fig. 5. For a wave polarized in the plane of the figure the voltage between the guide walls is divided at the branch, while the conduction currents are unaltered, so that the branch appears as a series junction. Thus, to get free transmission into the limb R the reflecting element in the limb T must present zero series impedance at the branch, and so must be situated at a distance from the equivalent plane of the branch equal to $\lambda_g/2$ (or a number of half-wavelengths), where λ_g is the wavelength in the guide. For a wave

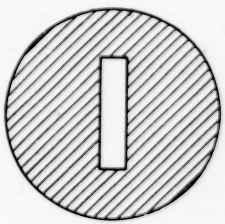
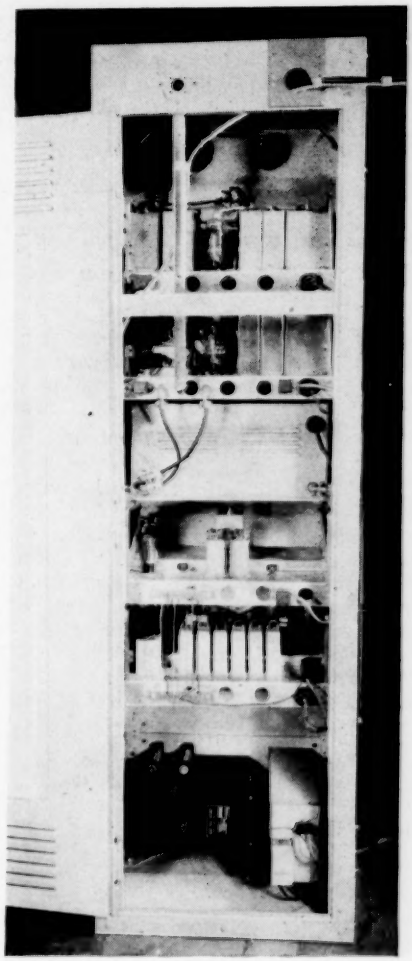


Fig. 4. *Polarization filter.*



Rear view of cabinet (door open).

polarized perpendicularly to the plane of Fig. 5, the branch appears as a parallel junction and the reflecting element must be placed at $\lambda_g/4$ distance (or an odd number of quarter-wavelengths) from the equivalent plane in order to provide a high parallel

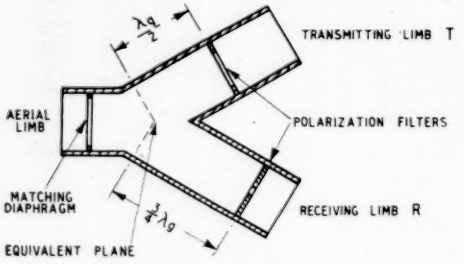


Fig. 5. *Section of* Y*-branch.*

impedance at the entrance to the unwanted limb.

This is an idealized explanation of the operation of the branch, and the exact positions of the diaphragms must be found by experiment. Because of distortion of the wave at the discontinuities in the tube perfect transmission is not obtained, and as a result standing waves are set up. These may be largely removed by a suitable reactance in the form of a diaphragm placed at the junction. With a waveguide of $\frac{7}{8}$in diameter and a branch angle of 60°, the standing-wave ratios obtained were 1.6 in the series junction and 1.3 in the parallel junction. The loss of power due to reflections of this order is only about 5 per cent and 2 per cent respectively. Fig. 6, (a) and (b), shows the arrangement of the components mounted on the branch.

2.2. *Transmitter*

It is not usually practicable to use amplitude modulation with centimetre-wave oscillators because of the associated frequency modulation produced. A method of overcoming this difficulty is fully to modulate the carrier with a rectangular wave of a constant supersonic frequency, whose pulses are modulated in width by the audio frequency. The transmitter is then oscillating at constant amplitude during the "on" period of the rectangular wave and not oscillating during the "off" period. With this method the mean carrier power is modulated at audio frequency, and the signal can be detected on a receiver designed for the reception of normal amplitude-modulated signals provided it has sufficient bandwidth. This is the simplest of several possible methods of pulse modulation.[4]

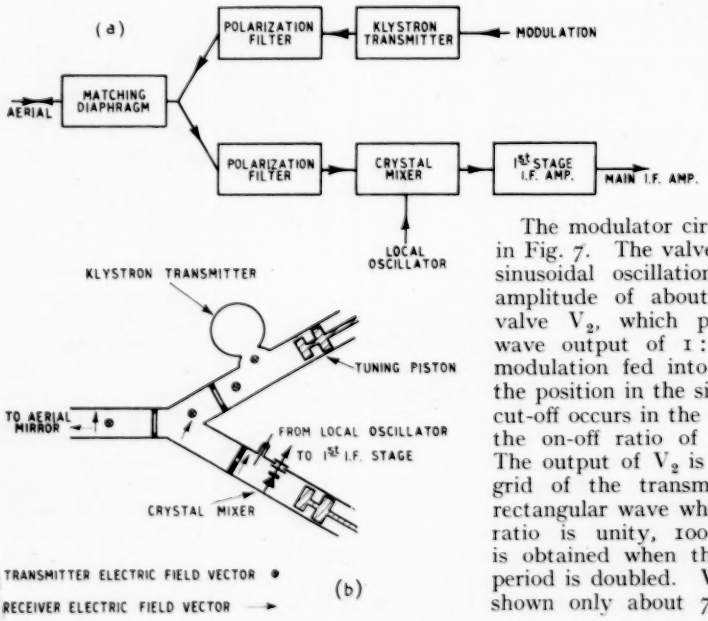


Fig. 6 (left) (a) *Duplex branch schematic.* (b) *Section of duplex branch.*

The modulator circuit is shown in outline in Fig. 7. The valve V_1 generates a 17-kc/s sinusoidal oscillation. This is fed at an amplitude of about 50 V into a limiting valve V_2, which produces a rectangular wave output of 1 : 1 on-off ratio. Audio modulation fed into the grid of V_2 alters the position in the sine-wave cycle at which cut-off occurs in the valve, and hence varies the on-off ratio of the rectangular wave. The output of V_2 is applied directly to the grid of the transmitting valve. With a rectangular wave whose unmodulated on-off ratio is unity, 100 per cent modulation is obtained when the value of the "on" period is doubled. With the simple system shown only about 75 per cent modulation

depth can be reached before noticeable speech distortion occurs. This is due to the fact that modulation is done on a sinusoidal oscillation. If the circuit of V_1 is replaced by a saw-tooth oscillator followed by more perfect squaring stages, linear modulation up to 100 per cent may be obtained.

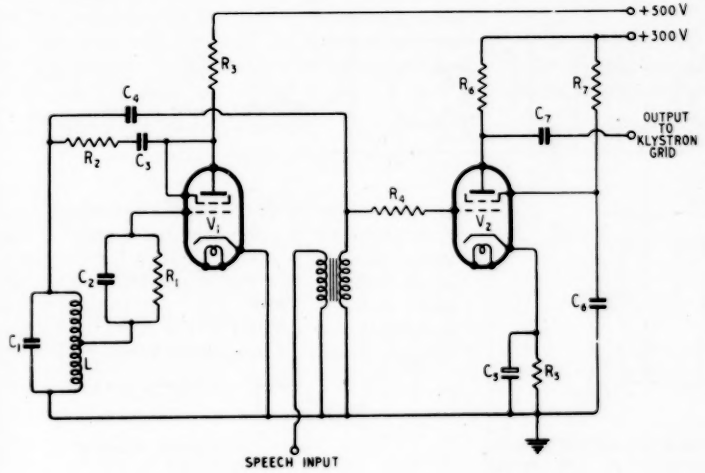


Fig. 7.
Modulator circuit;
$V_{1,2}$ 6V6; R_1 100kΩ, R_2 47kΩ, R_3 33kΩ, R_4 100kΩ, R_5 470Ω, R_6 3kΩ, R_7 15kΩ; C_1 0.0005 μF, $C_{2,3}$ 0.1μF, C_4 0.0005μF, C_5 25μF, C_6 1μF, C_7 2μF; L 150 mH.

The transmitting valve is a reflex klystron, a CV129 modified to have a waveguide output, which covers a frequency range of about 4 per cent around 9,400 Mc/s (3.2 cm). Tuning is done by mechanical deformation of the resonator cavity. The valve is mounted on the transmitting limb of the aerial system, the resonator being bolted directly to the waveguide as shown in Fig. 6(b). The power is fed into the waveguide through a tapered slot, and matching adjustment is made by the adjustable piston shown in the figure. The mean power output is about 75 milliwatts.

The power supply for the transmitter, which is combined in one unit with the modulator, provides a resonator-cathode voltage of 1,600 V, and a variable supply (300-500 V negative to cathode) for the reflector electrode. The potential of the latter must be adjusted to the appropriate value to produce oscillation. The controls are two potential dividers, one a bias control, the other the reflector voltage control. There is also a gain control for the speech amplifier, and a switch by which the 17-kc/s square-wave modulation can be altered to 1 kc/s, for use as a test signal.

2.3. *Receiver*

The superheterodyne receiver consists of three units: the crystal mixer and first stage i.f. amplifier; the local oscillator and power supply; the i.f. amplifier and l.f. stages.

The first unit is mounted on the receiving branch of the aerial system, Fig. 6 (b). The crystal mixer valve (CV112) is placed across the waveguide and tuned by a filter piston situated behind it. The crystal impedance at this frequency is such that in a $\frac{7}{8}$-in guide a single tuning reactance is sufficient to ensure an adequate match. The live end of the crystal is connected through an r.f. filter to the input circuit of an i.f. amplifying stage. The output of this amplifier is transformer-coupled to a coaxial cable leading to the main i.f. amplifier.

The main i.f. amplifier has four stages with an overall bandwidth of 3 Mc/s centred on 13.5 Mc/s and is followed by the second detector and two l.f. stages. With the type of modulation used at the transmitter both the speech signals and the 17-kc/s square wave are present in the output after detection. The two are separated by a filter in the last l.f. stage. The 17-kc/s signal is rectified and used to provide automatic-gain control on all stages. This gives an output characteristic which rises sharply with input voltage for small signals, and flattens off to give a substantially constant output amplitude for signals stronger than about 20 db above noise level.

For automatic-frequency control a double-diode discriminator with a bandwidth of 0.2 Mc/s is fed from the fourth i.f. stage through a further stage of amplification and is connected by blocking capacitors to a second double-diode rectifier as shown in Fig. 8. With this arrangement the a.f.c. voltage is derived from the 17-kc/s modula-

tion and not directly from the carrier. The removal of the d.c. component by the blocking capacitors largely prevents the unbalanced noise voltage, which arises from any asymmetry in the frequency-response

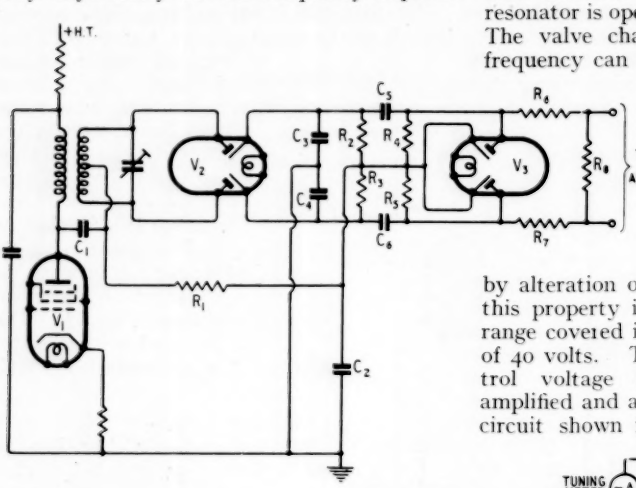


Fig. 8.
Receiver a.f.c. circuit;
V_1 VR91, $V_{2,3}$ D63; R_1 47kΩ, $R_{2,3}$ 100kΩ, $R_{4,5,6,7,8}$ 220kΩ; $C_{1,2}$ 0.0005μF, $C_{3,4}$ 0.0002μF, $C_{5,6}$ 0.1μF.

characteristic of the receiver, from taking control of the discriminator at low signal levels with consequent loss of the signal. The frequency-control voltage, obtained after rectification in the second double-diode, is applied to the local oscillator through a d.c. amplifier on the oscillator panel.

The valve used as local oscillator (CV130) is also a reflex klystron. It requires a resonator-cathode voltage of 1,200 V, with the reflector approximately 300 V negative to cathode. It is supported from the panel on a mounting plate removable from the front. The power is fed from the resonator output slot into a waveguide fitted with a choke cavity C to minimize external leakage at the junction. The waveguide feeds a coaxial cable through a probe transformer P, and coupling to this is varied by means of a reflecting piston R adjustable from the panel. This arrangement is shown schematically in Fig. 9.

The coaxial cable feeds a waveguide fixed to the back of the cabinet, and this terminates close to the aerial system. To allow flexibility for adjustments of mirror direction the connection to the crystal is made by another short length of coaxial cable. This terminates in a probe projecting into the aerial receiving branch close to the crystal and loosely coupled to it. The local-oscillator drive is adjusted to produce a rectified crystal current of between 50 and 500 μA; within these limits the actual value is not critical.

The screw mechanism which tunes the local-oscillator valve by deformation of the resonator is operated by a knob on the panel. The valve characteristic is such that the frequency can be varied over a small range by alteration of the reflector potential, and this property is used for fine tuning. The range covered is about 20 Mc/s for a change of 40 volts. The automatic-frequency control voltage from the discriminator is amplified and applied to the reflector by the circuit shown in simplified form in Fig. 9.

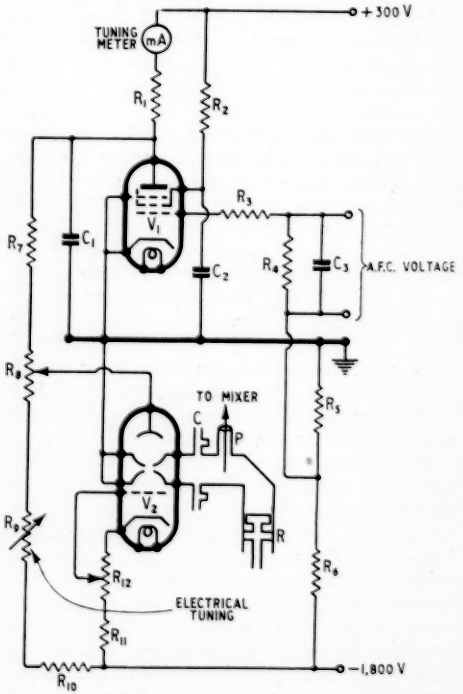


Fig. 9. *Local oscillator circuit;*
V_1 VR91, V_2 CV130; $R_{1,2}$ 47kΩ, R_3 10kΩ, R_4 470kΩ, R_5 680Ω, R_6 220kΩ, R_7 1.5MΩ, R_8 250kΩ, R_9 50kΩ, R_{10} 150kΩ, R_{11} 48kΩ, R_{12} 15kΩ; C_1 0.002 μF, C_2 0.1μF, C_3 0.002 μF.

The output voltage change from the d.c. amplifier is used to vary the current through the potential-divider chain which supplies the steady reflector potential, and hence to produce voltage variations of suitable magnitude between reflector and cathode. A meter measuring the anode current of the d.c. amplifier serves as a tuning indicator. The deviation of the meter from its normal value is an indication of the amount and sign of frequency compensation being supplied by the control circuit.

2.4. *Relay and Control Circuits*

With any radio-telephone system the design of the terminal equipment will depend entirely on individual requirements, which may range from a single telephone termination to a multichannel carrier-telephony system. The present equipment is intended to carry only a single speech channel, but this may be presented in a number of forms. The requirement in one instance was for a telephone at a short distance from the equipment, with facilities for the extension of the call through a small private branch exchange to an external two-wire line. The circuit arrangement used in this case is shown in simplified form in Fig. 10.

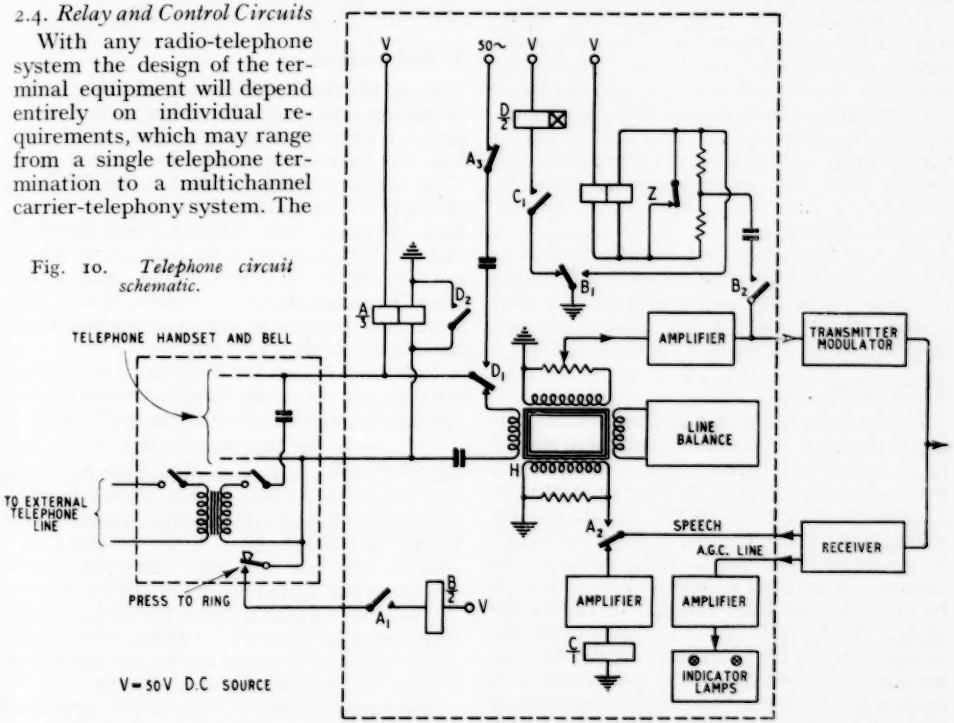


Fig. 10. *Telephone circuit schematic.*

The telephone instrument is similar to a G.P.O. type, but differs internally in having a connection for an external line through a transformer and switch, a push-button key for ringing and a bell operating from the 50-c/s a.c. supply. The other components shown in the figure are contained in two units on the rack.

The two-wire line from the telephone is connected to the transmitter modulator and receiver output through a hybrid transformer H. Removal of the handset from its cradle at the station originating a call operates a balanced-relay A/3, disconnecting the incoming ringing circuit and making the circuit connections for outgoing ringing. The " ring " button on the telephone is now pressed, thereby operating, by means of a relay B/2, a tone vibrator Z which transmits a 120-c/s note to the modulator. This note received at the other end of the link operates the vibrator C/1 tuned to the same frequency as vibrator Z. When C/1 has built up a sufficient amplitude its contacts operate a slow-operating relay D/2 which applies a ringing voltage to the bell. Lifting of the handset at this station cuts off ringing and switches over the receiver output to the

handset earpiece; contact between the two stations is then established.

The operator can extend the call to an internal or external line by means of the switch on the telephone instrument.

The equipment is provided with a simple signal-strength indicator. The automatic-gain control voltage is amplified and made to operate a relay controlling a red and a green lamp. If the received signal-strength falls below a predetermined value the green light changes to red, indicating that the signal is below good operational level.

In its existing form the equipment suffers somewhat by the retention of features from earlier experimental apparatus. It is considerably larger than need be, and has since been redesigned to be housed in a 3-ft cabinet instead of a 6-ft one. Again, if intended to work within a small assigned waveband, the duplex filter and feeding system could be reduced in size, and made in a simpler mechanical form.

The low-frequency part is entirely dependent on particular requirements. It could be arranged to operate on any normal telephone system of ringing and exchange working, or as a link in a repeater chain.

3. Operation

It has been pointed out that with centimetre waves it is desirable that there should be an optical path between the aerial mirrors. For a short link it may be easy to locate the equipment rack close to the aerial, but for a long link, where considerable aerial height is necessary, the aerial may have to be situated on a tower or on the roof of a high building remote from the rest of the equipment. Under the latter circumstances the equipment already described would have to be modified, but the sites on which this system has been used allowed the equipment rack to be placed close to the aerial, which radiated through an aperture in the wall of the room, the opening being covered with Perspex or water-proofed canvas.

In setting up, the aerials must be directed visually or by compass bearing to an accuracy of $\pm 1^\circ$ in azimuth and elevation. After the signal is received, tuning is adjusted until the a.f.c. amplifier meter indicates exact tune. During the first hour after switching on, the transmitter and local oscillator will drift in frequency by a few megacycles per second, and tuning may have to be re-adjusted. Thereafter the changes are small and well within the holding range of the automatic-frequency control. Correction of frequency drift can be made at intervals by the fine tuning control.

The power supplies are not fully stabilized internally, but it is advantageous to have the mains power supplied through a constant-voltage transformer.

The ringing relays will operate on a signal with a mean power about 10 db above noise level, but as speech is not fully intelligible below a signal-to-noise ratio of about 20 db the warning light relay is best set to operate somewhat above the latter level.

4. Performance

Most of the experience with the radio-telephone equipment has been gained on a path of some 57 miles over sea, where the link has been in operation for over a year. This equipment was built for the Ministry of Supply, to provide telephone communication between two S.R.D.E. experimental stations.[1] The ends of the link are at Rhiw, near Pwllheli, in North Wales, and a site near Strumble Head in South Wales, the respective heights of the stations above sea level being 825ft and 540ft.

If h_1 and h_2 are the heights of the transmitting and receiving aerials, the maximum optical distance between them is given by

$$d = (2R_e)^{\frac{1}{2}}(\sqrt{h_1} + \sqrt{h_2}),$$

where R_e is the effective radius of the earth. The effective radius, which allows for the bending of the rays due to the variation with height of the refractive index of the atmosphere, has an average value of about 1.3 times the actual radius of the earth.

Thus the optical distance for aerials at the heights quoted above is 73 miles. The actual path length of 57 miles across Cardigan Bay is thus well within the optical range.

The carrier power P_r received by a receiver situated in free space at a distance d from a transmitter of radiated power P_t is given[5] by

$$P_r = \left(\frac{3\lambda}{8\pi d}\right)^2 P_t G_t G_r,$$

where G_t and G_r are the actual aerial power gains referred to a Hertzian dipole. It has been shown[1] that over a path of the nature considered the calculated free-space field gives a good approximation to the average field actually received.

With a mean transmitted power of 75 milliwatts, and aerial gains of 5,700 the received energy over a 57-mile path in free

space should be about 4,200 $\mu\mu$W (which would correspond to a voltage in a 75-ohm cable of 55 db above a microvolt). With a receiver noise factor[5] N of 10 db, and a bandwidth B of 3 Mc/s, the effective noise power p at the input will be given by $N = 10 \log_{10} (250\, p/B)$; i.e., $p = 0.12$ $\mu\mu$W. Hence the signal-to-noise ratio at the second detector will be about 45 db. The subsequent improvement due to the l.f. bandwidth of 5 kc/s is given approximately by a factor equal to the square root of the ratio of i.f. to l.f. bandwidths, and is thus about 14 db. The signal-to-noise ratio at the receiver output will therefore be about 59 db.

At these wavelengths no interference has been experienced from electrical machinery or atmospheric static, and in practice overall signal-to-noise ratios of the order of 55 db were consistently obtained. In this installation the telephone is situated beside a small exchange board to which the extension line is connected. By this means calls can be extended to an external G.P.O. line. The signal-to-noise ratio is adequate for this purpose, and long extensions by trunk lines have been made, for example, to Scotland and London.

Over a path of this length, even though it is optical, transmission is not constant, and both rapid and slow fading do occur. The effect for this path has been described in detail elsewhere.[1] Generally the variations, which occur mainly during fine weather, are within a range of $\pm$ 10 db and the effectiveness of the automatic-gain control makes them unobservable. Under certain atmospheric conditions, however, very deep rapid fading takes place. When this occurs the signal falls in two or three seconds from its normal value to a value often below noise level, and rises almost immediately and just as rapidly to its former level. This may take place at several-minute intervals over a period of perhaps an hour. In practice such fades are not particularly troublesome, for their incidence is always obvious by the sharp rise in noise level, and one merely stops speaking for the few seconds until the carrier rises sufficiently to suppress the noise. Fading of this nature is not common, and represents a loss of not more than 0.1 per cent of communication time.

Short-range tests have been made over distances of a few miles. In these cases the signal-to-noise ratio was extremely high, the noise being almost completely suppressed by the automatic-gain control.

In its earlier experimental form, apparatus of this type has worked successfully from the top of Mt. Snowdon to Aberporth in Cardiganshire, a distance of about 70 miles over land and sea, and from the roof of the G.E.C. Research Laboratories at Wembley to a building in an Admiralty Establishment at Haslemere, Surrey. The latter path[1] is only 38 miles long, but is obstructed by houses and trees near the Wembley end, so that the signal is received after diffraction round these obstacles. In these circumstances the received signal was only some 12 db above noise level, which is near the limit of intelligibility.

The general conclusion is that, with an output power of about a tenth of a watt, optical distances of the order of 60 miles can be covered satisfactorily with a single channel link. For much shorter distances the diameter of the mirror could be reduced. As the distance is increased, with corresponding increase of aerial height, the degree of fading will also increase, so that very long paths, even though they are optical, are likely to give somewhat variable results, particularly over sea. For these a longer wavelength will be more satisfactory, but the compactness of the duplex aerial system will be lost.

APPENDIX

Gain of a Paraboloid Reflector

An approximate formula for the gain of a paraboloid can be simply derived as follows. Let the total power radiated from the paraboloid be P, and let the source be such that all the energy from it is directed towards the reflector so that the radiated power density is uniform over the aperture. Then the energy density W_0 across the aperture area A is given by $W_0 = P/A$. If the electric field corresponding to W_0 is E_0, then, by the optical theory of diffraction from a circular opening of radius a, the field E received at a distance d and angle θ to the normal is known to be

$$E = \frac{E_0 a}{d \sin\theta} J_1 \{(2\pi a/\lambda) \sin\theta\}$$

$$= \frac{A}{\lambda d} E_0, \text{ when } \theta \to 0.$$

Hence the energy density W at a point along the normal is

$$W = \left(\frac{A}{\lambda d}\right)^2 W_0.$$

The energy density W_1 received at a distance d from an omni-directional source also radiating a power P would be

$$W_1 = \frac{P}{4\pi d^2}.$$

Hence the power gain is

$$G = \frac{W}{W_1} = \frac{4\pi A}{\lambda^2}.$$

Expressed with respect to a Hertzian dipole this is reduced by a factor of $2/3$ to $8\pi A/3\lambda^2$.

When $x = 1.616$, $J_1(x)/x$ is reduced to a value of 0.707 times its value at $x = 0$; hence the above expression for E shows that the half-power points occur at an angle θ given by

$(2\pi a/\lambda) \sin \theta = 1.616$; i.e., at $\theta = \sin^{-1}(0.26\lambda/a)$.

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[3] H. Archer-Thomson and E. M. Hickin, "Radio Technique and Apparatus for the Study of Centimetre Wave Propagation," *J. Instn elect. Engrs*, 1946, Vol. 93, Part IIIA (in process of publication.)

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[5] R. J. Clayton, J. E. Houldin, H. R. L. Lamont and W. E. Willshaw, "Radio Measurements in the Decimetre and Centimetre Wavebands," *J. Instn elect Engrs*, 1946, Vol. 93, part III, p. 97.

CORRESPONDENCE

Letters of technical interest are always welcome. In publishing such communications the Editors do not necessarily endorse any technical or general statements which they may contain.

Amplitude and Frequency Modulation

SIR,—I should like to take issue with the apparent implication of the Editorial appearing in the July 1947 issue of *Wireless Engineer*. Although it is desirable to view new methods with a conservative eye before pressing for their general adoption, the comparison between frequency modulation and amplitude modulation often seems obscured by a confusion as to their end use. It is sometimes helpful to consider whether the use is communications or entertainment broadcasting.

For a direct comparison between an a.m. and an f.m. system, may I direct your attention to a two-part article entitled "Field Tests of Frequency and Amplitude-Modulation With Ultra-High Frequency Waves," by I. R. Weir in the *General Electric Review*, Vol. 42, No. 5, May 1939, page 188; and Vol. 42, No. 6, June 1939, page 270.

For your convenience, the advantages reported are summarized below:

"(1) Improved signal-plus-noise to noise ratio. Under some conditions this improvement is as high as 20 to 25 db. This means there is a remarkable freedom from atmospherics and man-made static, such as X-rays, automobile- and aircraft-engine ignition, commutator sparking, etc.

"(2) A more definite and uniform service area of a transmitter is established because frequency modulation signal-plus-noise to noise ratio remains high until the field intensity reaches a very low value.

"(3) Comparatively much smaller geographical interference area is obtained when two frequency-modulated transmitters are operated simultaneously on the same frequency than when amplitude-modulated transmitters are so operated.

"(4) A frequency-modulated radio-frequency amplifier is more efficient than one for amplitude modulation because frequency modulation can be accomplished at low level followed by class C power amplification.

"(5) A given service area can be covered with considerably less power than with amplitude modulation because of the improvements in signal-plus-noise to noise ratio obtained with frequency modulation.

"(6) For a given power output, small radio-frequency amplifier tubes can be used."

So far as broadcasting is concerned, you are doubtless by this time in possession of the brief paper by C. M. Jansky, Jr., entitled "The Demonstrated Potentialities of Frequency Modulation Broadcasting on Very High Frequencies." The paper was prepared for delegates to the International Telecommunications Conferences for use in connection with the f.m. demonstration given August 6th, 1947, at the Ambassador Hotel, Atlantic City, New Jersey.

Mr. Jansky's paper summarized the advantages inherent in f.m. broadcasting and particularly describes the conditions under which a test programme was broadcast to the delegates. The programme was heard in Atlantic City via station WBAB-FM which has employed a special receiving location to pick up the original broadcast from W2XEA-W2XMN at Alpine, New Jersey. The distance covered by radio was 110 miles. Special receiving antennas were 160 feet above sea level and the transmitting array 350 feet above sea level. However, the receiving antennas were 7,400 feet below lines-of-sight. W2XEA operates on 92.1 Mc/s. with approximately 20 kilowatts.

Before the war, the writer was employed by the Yankee Network, one of the pioneer f.m. broadcast organizations, and had an opportunity there to observe the success of the f.m. technique.

ALEXANDER A. MCKENZIE
Associate Editor,
Electronics.

New York, U.S.A.

ADVISORY COUNCIL OF SCIENTIFIC RESEARCH

Professor P. I. Dee, C.B.E., F.R.S., formerly Superintendent of the Telecommunications Research Establishment, has been appointed a member of the Advisory Council of Scientific and Industrial Research. He is Professor of Natural Philosophy at the University of Glasgow.

Sir William Griffiths, D.Sc., F.R.I.C., F.Inst.P., F.I.M., has also been appointed a member. He is Chairman and Managing Director of the Mond Nickel Co. and a Past-President of the Institute of Metals.

Professor Sir Lawrence Bragg, O.B.E., M.C., D.Sc., F.R.S., Professor Sir John Lennard-Jones, K.B.E., D.Sc., F.R.S., Sir Andrew McCance, D.Sc., F.R.S., and Sir Raymond Streat, C.B.E., retired on completion of their terms of office.

RADIOLYMPIA 1947

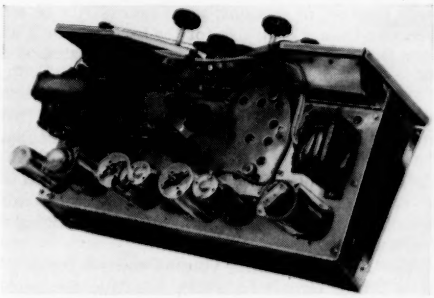
Fifteenth National Radio Exhibition

THE fifteenth National Radio Exhibition, in spite of restrictions and shortages, was much larger than its predecessors, and although broadcast receivers were still the staple exhibit, the scope of the show was much wider than hitherto. Whereas in the past the home market has always received first consideration, export models were very prominent this year and such sets are noteworthy for the considerable degree of tropicalization incorporated in them. This tendency was so general that it has been thought unnecessary to mention it in the individual sets referred to below.

Broadcast Receivers

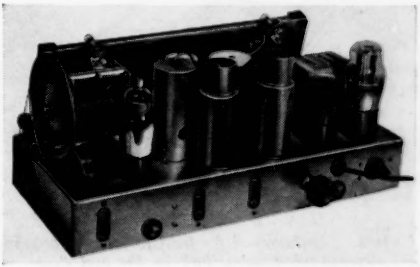
Although the stereotyped 4 + 1 valve set was the " bread-and-butter " line with most exhibitors, and will be taken for granted, the signs of a break-away from this austere framework were more numerous and varied than one had dared to expect. The outstanding tendencies were better short-wave reception, higher quality of reproduction, and in all kinds of apparatus a greatly improved standard of mechanical design and construction. Progress could also be seen towards more economical production and easier servicing.

Instead of trying to cover all short waves in one band, many set makers now split them up into anything from two to ten. Although this is sometimes used to extend the total frequency coverage, the main object is to facilitate tuning. Some models provide continuous coverage in several broad bands, sometimes with the further tuning aid of mechanical band-spread such as a two-speed drive and auxiliary logging scale (Peto-Scott), while others select the narrow broadcast allocations only, spreading each over the full tuning scale.



Bush export model EBS4 chassis.

The H.M.V. Model 1700 does both, giving the option of tuning all short waves in three bands, or the broadcast sections only in seven bands, in addition of course to the usual medium and long. Spreading the broadcast bands over the full tuning scale necessitates some circuit device for reducing the tuning ratio. In the Ace Model A600 the lowest in frequency of the seven short-wave bands (6 Mc/s) is permeability-tuned, and the remainder are covered by switching coils in parallel. Others, such as Aerodyne and Alba, employ a split gang-capacitor. The full capacitance is used for long, medium, and 3-7.5 Mc/s, and the small section for six broadcast bands up to 27 Mc/s. Murphy, Ekco and R.G.D. are other examples of multiple band-spread. The work of searching over all these bands is in some cases alleviated by fly-wheel tuning.



Regentone Type A358 broadcast receiver chassis.

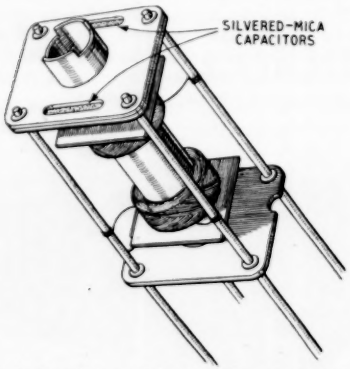
Concurrently with band spreading is a very general increase in size and clarity of scales. The Ultra T44T, for example, has six bands scaled on a horizontal cylinder rotating with the band-change switch, giving for each band a scale 11in × 2in, clearly marked in station names, metres and frequencies.

To provide the needed signal/noise ratio and image ratio for short waves, a number of models include an r.f. stage on these bands only.

The foregoing improvements would, of course, be largely nullified by inconstancy of tuned circuits, and the stringent requirements of war have provided valuable experience. Temperature compensation by negative-coefficient capacitors has long been used, of course, but there are also some examples of inductance stabilization, and the design of trimmers has noticeably improved. The trend towards iron cores for i.f. and even r.f. coils, largely for compactness but also to simplify adjustment, is very marked. And permeability tuning is slowly gaining ground ; an example is the very low-priced Pye car receiver.

Push-button tuning, so common before the War, has largely had to drop out or be simplified, in the interests of economy. Motor tuning has almost entirely disappeared, and the number of pre-selected stations is generally small. In the Ferranti sets two are provided by extra positions on the wave-

band switch, and selection is facilitated by calibration scales on the iron-core adjusters. As an overwhelming proportion of listening is done on Home and Light services, this is a common-sense arrangement. The desirability of push-button control for car radio is obvious, and in the Radiomobile model tone and band-change are effected in this way, and the station selected by any of the four remaining buttons which, acting mechanically on the gang capacitor, can quickly be changed from the front of the panel by slackening the button and retightening after tuning-in the new station.



United Insulators i.f. transformer embodying silvered-mica capacitors in the end plate.

It is an almost daily experience for many listeners to miss some desired programme by failing to remember to switch on in time. Several receivers are now available with clock-controlled switches. The most elaborate system is in the H.M.V. Model 1700, with three clocks enabling any 24-hour combination of three sessions from two stations to be selected in advance. In the Ekco " Radiotime " a single clock switches on and off for reception from any of six stations, and, in the absence of a carrier wave, sounds an alarm. The Bennet and Goblin models switch on any programme to which the set is tuned, a facility that can be added to existing sets by the Ekco CC65 switching clock, which is rated to control up to 300 watts. As the systems mentioned all use 12-hour clock faces, a 2 : 1 gear is used, in conjunction with an indicator, to enable a.m. and p.m. to be distinguished.

A good example of the way in which servicing has been provided for in the design is the Ultra T49. The chassis is mounted entirely on a strong baseboard, so that the moulded cabinet is not only quickly removable, but, as it carries no part of the weight, is less likely to be broken. The chassis is hinged in two places, and, when opened out, all the important points for testing and adjustment are easily accessible. Although plug-in electrolytic capacitors are still rare, provision is made in some sets (Ferranti) for easy replacement by slackening the clip and withdrawing the flex leads.

In spite of shortage of materials, the standard of external appearance is undoubtedly higher than before the War. Some fine examples of wood cabinet were seen, such as the Decola " Knightsbridge." But the most general advance is in the mouldings, which in both colour and design contrast brightly with the lumpy brown affairs of pre-war days.

The miniature trend not only has obvious advantages when exemplified in portables, " personal " sets, and deaf aids, but it contributes to economy in materials. A good example of economy both in materials and labour is the United Insulators silvered-mica twin capacitor made up into the form of an i.f. transformer end-plate. The four corner wires of the transformer have only to be soldered to the four eyelets in the plate to complete the framework and at the same time the connections of primary and secondary tuning capacitors (which incidentally are kept away from the magnetic field) to their respective coils. Ceramic capacitors, so increasingly used for v.h.f., are now available more cheaply and compactly in flat form. Bush or " feed-through " capacitors simplify the assembly in many positions. Economy in production is combined with diversity of style in the Plessey " Universal " tuning drive, whereby standard parts produced from a single set of tools can be assembled to give a great variety of units, with scales horizontal, vertical, " clock," or arc, and with various arrangements and numbers of fixed or moving pilot lamps.

A useful component in a.c./d.c. sets is the Brimar thermistor, in appearance like an ordinary carbon resistor, which can be connected in series with the heater circuit to prevent heavy mortality among pilot lamps owing to the low resistance of the circuit when cold.

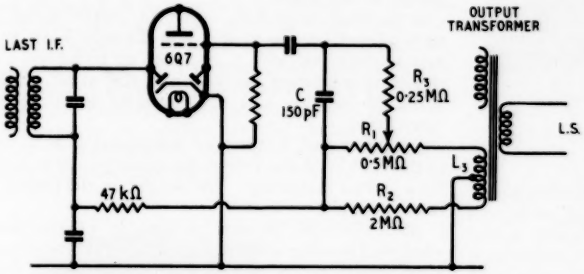
Attention devoted to audio reproduction can be considered under three heads—variable-selectivity and tone control systems, output stages, and loudspeakers.

The general purpose set, intended for receiving a large number of stations, must necessarily be more selective than is desirable for the local station ; and, even if variable selectivity is fitted, few listeners can be relied upon to use it intelligently. In the Bush " Bi-Focal " system, some degree of audio bandwidth expansion is automatically obtained by a volume control that introduces negative feedback. On account of the limited effectiveness of a.g.c. in the simpler types of receiver, it can be assumed that it is necessary to reduce gain manually when listening to the local station, thereby bringing the feedback into operation.

The Kolster-Brandes volume control forms part of a bridge circuit in which negative feedback is progressively increased as the control is turned towards minimum. At the same time the proportion of top frequencies is augmented by a by-pass capacitor.

An example of the more elaborate models, where flexible control is appropriate, is the Dynatron, in which a selectivity control, operating on a tertiary i.f. winding, provides i.f. bandwidths up

to 25 kc/s. To enable this to be used without heterodyne interference there is a whistle filter giving 35 db attenuation from the level at 9,000 ± 500 c/s. The tertiary-winding method is also used by R.G.D. in a 3-position selectivity switch; while the tone control switch in the Ace sets has a fourth position in which bottom-capacitance i.f. coupling is introduced to broaden the bandwidth to 20 kc/s.



Kolster-Brandes volume control with negative feedback.

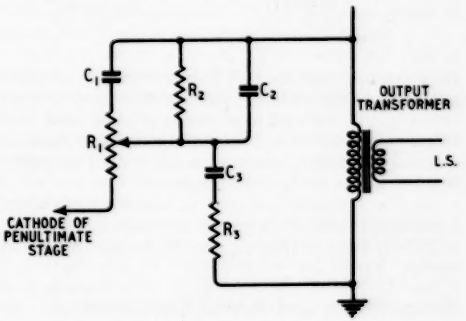
The R.G.D. tone control employs frequency-discriminating negative feedback. With the slider in the lowest position, the resistance-capacitance potential divider feeds back both top and bottom frequencies, narrowing the audio band but preserving a reasonable balance. At the other end, top is restored and there is some bass boost due to C1.

Push-pull output is used in practically all the more luxurious models and even in some of the cheaper ones where a single pentode used to be standard; and the varieties of negative feedback are very numerous. The Regentone push-pull stage is its own phase inverter, as one of the output valves derives its grid drive from the screen of the other. The Lowther A10F and A15F amplifiers, on the other hand, have an exceptionally elaborate push-pull system, with a cathode-coupled phase inverter followed by a push-pull driver stage in which a pentode in the common cathode lead stabilizes the balance.

Most of the devices used for improving the frequency range and reducing non-linear and transient distortion in loudspeakers are well-known in principle, but have not hitherto been put into practice in so many exhibits. Several examples of the high-note diffuser and acoustic labyrinth or similar treatment for the bass were shown. Instead of cutting away the baffle board over the whole area of the cone, Kolster-Brandes leave only a vertical slot about $1\frac{3}{4}$-in wide (i.e., not more than $\lambda/2$ for the high a.f.), giving better diffusion in the horizontal plane, and at the same time the extra air loading lowers the bass resonance slightly. In another model, the loudspeaker axis is downward and diffusion is obtained by a conical reflector. Murphy use an acoustic resistance of corrugated cardboard to avoid resonance in large cabinets; while their "baffle-board" receivers have frequency-discriminating negative feedback to boost the otherwise insufficient bass. Loudspeaker and cabinet resonance are controlled in the Acoustical "Concert Labyrinth" by an acoustic network adjusted to suit ordinary room environment. The Wharfedale "Varitone" has a bass phase-inversion opening at the foot of the cabinet which can be closed when listening to speech.

In a number of reproducers, from two to four loudspeaker units are used, with a cross-over filter to prevent overloading and intermodulation. In the General Electrical Radio GER/G24 separate channels are provided for 16–2,000 c/s and 2,000–16,000 c/s, and there are three speaker units with separate controls for bass, middle, and top frequencies. The Tannoy dual loudspeaker consists of two concentric units energized by the same magnet—a central horn-loaded unit for frequencies above 1,000 c/s, and a cone type for those below. The cone is shaped to continue the horn contour as a flare.

Twin-diaphragm technique is exemplified by one of the many Goodman models. Another is the Lowther-Voigt, which is notable also for the remarkable flux density of 19,000 gauss, obtained by skilful use of Ticonal alloy.

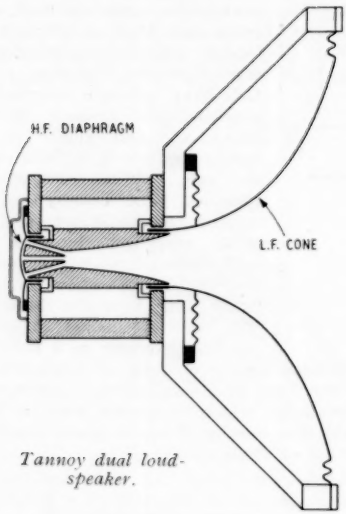


Negative feedback tone control used by R.G.D.

Although not directly connected with fidelity, the central-magnet construction adopted by Plessey and others minimizes the external field, which is otherwise apt to be troublesome in television sets. A similar result, with unusual compactness, is achieved in the Truvox "Wafer" loudspeaker, in which the cone contains the magnet.

In the absence of a regular service of frequency-modulation broadcasting in this country, provision for it is not to be expected in receivers; but a prototype 14-valve Ambassador was shown, which included f.m. and a.m. reception on 32–52 and 72–112 Mc/s. Reception of the B.B.C. experimental f.m. on 90 Mc/s is also provided in the H.M.V. Model 1700 radio-gramophone, which would need a

whole article for a mere description. It is a 43-valve 12-waveband set, and besides the band-spread and time-switching already mentioned, its features include gramophone reproduction up to 14,000 c/s, two r.f. stages on short waves, motor push-button tuning and cruise tuning, a.f.c. on all wavebands, muting until within 2 kc/s of resonance, output



Tannoy dual loud-speaker.

stage comprising four KT66 valves in parallel-push-pull feeding a horn-loaded ribbon loud speaker above 5,000 c/s and one medium cone and two larger ones for the lower frequencies. Remote control of stations and automatic record changing is provided at a chair-side pedestal.

At the opposite extreme a broadcast receiver, permeability-tuned over the medium band, using a B.T-H. silicon detector, was shown in the form of a pen.

Gramophones and Sound Equipment

Few exhibitors of radio-gramophones did not include automatic record-changing models, and nearly half showed no other kind. This is because of the much simpler and more compact changers now available. The Plessey model differs little in size or appearance from the ordinary turntable, except for the centre spindle, which projects to a maximum height of 4¼in above the motor board, and has a collapsible collar on which up to eight mixed 10-in and 12-in records can be placed. Any record can be repeated or rejected.

In many radio-gramophones the turntable is on a floating mounting to avoid motor rumble.

The tendencies in pick-up design are: to use sapphire points, to reduce the pressure on the record, and to widen the range of uniform frequency response. There are several new Truvox models, oi whfch details of mechanical construction are not yet available, but the BP20A is stated to have a ribbon type of movement with a total weight, including sapphire stylus, of only 40 mgm, and to be within 3 db from 25 to over 20,000 c/s. There are also two Truvox moving-coil types with sapphire points and wide frequency response.

The high-fidelity Decca pick-up hitherto fitted only in the luxurious Decola reproducer is now available separately and also in a moderately priced table model.

A moving-coil pick-up based on Voigt's design is now offered by Lowther; and Tannoy have two new models, one with a response up to 10,000 c/s, requiring miniature needles, and the other taking standard needles and substantially level up to 7,000 c/s.

Lightness and freedom of movement is achieved in the H.M.V. Model 1700 radio-gramophone pick-up by a gimbal mounting. The weight on the record is only 8 grams.

Although the Plessey pick-up is of the conventional moving-iron type, its magnet is interesting, being made of the new magnetic material, "Casiox," which consists of a mixture of iron and cobalt oxides and a small quantity of plastic binder.

High fidelity in pick-ups and microphones is generally at the expense of output. The Truvox ribbon type, for example, when used with bass correction for standard recordings, yields only 8mV at the secondary of a 1:60 transformer. With high audio gain it is difficult to avoid hum from a.c. valve heaters; but in the McMurdo 10-watt amplifier this problem is solved by heating the first three valves with a 1-Mc/s supply obtained from a screened oscillator.

Public-address and other audio amplifiers follow mainly well-known practice; but the Trix U885 is notable with an output of 20/25 watts from 200/250-volt a.c./d.c. supplies, using an output stage of four CL33 valves in parallel-push-pull. Volume expansion, for giving a wider dynamic range from records, was not conspicuous at the Show; but the opposite process, volume compression, to prevent overloading of public-address equipment, is included in the Acoustical M9190-watt amplifier, in which the limiting output is adjustable.

B.T-H. permeability tuned "fountain-pen" crystal set.

The extensive wartime use of sound recording has led to the appearance of a large amount of well-engineered equipment in this category.

Acetate disk recorders follow mainly familiar lines, and chief interest attaches to those using iron-oxide-impregnated plastic film. Two examples were shown by G.E.C.; one for home use, with "medium fidelity" (i.e., up to 6,000 c/s), giving 30 minutes playing time on one reel of tape; the other, with tape travelling at a higher speed (but equal playing time) reproduces up to 10,000 c/s.

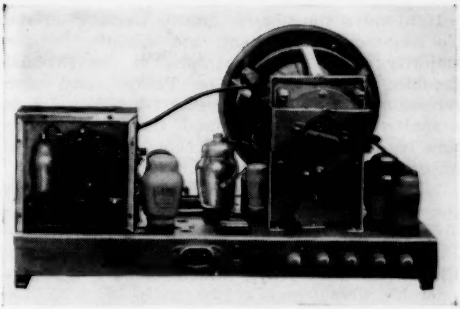
An entirely different use of similar material is seen in two E.M.I. recorders for dictating, one for office use and the other portable. In both, the plastic film is in disk form, and the spiral path of the magnetizing head is controlled by a grooved solid disk of small diameter placed on top of the plastic. A coupled indicator enables any point on the record to be marked for the guidance of the typist. One miniature unit serves both as microphone and play-back earpiece. Each disk provides

E.M.I. portable recorder for dictation; a flexible magnetic plastic disk is used.

three minutes recording, and can be wiped clean and used at least 1,000 times. The portable model has a 3-valve all-dry-battery driven amplifier.

Television

Although there is now little variety in the type of screen, nearly all being directly-viewed 9-in or 12-in c.r. tubes (with a small sprinkling of 10-in and 15-in), circuit arrangement is so far from standardized that it is difficult to find two makes alike even in valve sequence. Straight sets outnumber superheterodynes; but Cossor combines both, with a 2.2-Mc/s i.f. superheterodyne for sound and a



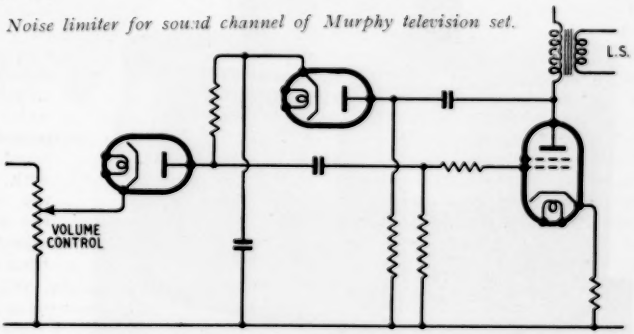
Ekco television set with 140-kc/s oscillator for e.h.t. source.

5-stage straight r.f. amplifier for vision. Ferranti and Bush have four r.f. stages for vision, with a sound superheterodyne branching off after the second stage. In most of the superheterodynes the frequency changer is common to sound and vision, but the Philips sets have separate frequency changers preceded by one common r.f. stage. In the straight types, some (e.g., Philco and Sobell) have separate channels; others have one (Pilot) or more (Ferguson) stages in common. There is a tendency to use vestigial sideband reception in both straight and superheterodyne types, for combining adequate vision bandwith with freedom from sound interference. Various sound channel filters are used in the dual-sideband types.

One v.f. stage is usual. The Cossor set uses a cathode follower, and Baird is notable in having two diode detectors in push-pull feeding a push-pull v.f. stage driving cathode and grid of the c.r.t. oppositely. The object is to ensure sufficient output to modulate the tube fully, notwithstanding 7 kV on the anode for giving an exceptionally bright picture.

Most models have some form of noise suppression on sound and/or vision, if only a simple limiter to prevent the c.r. tube from being driven beyond normal maximum white. A few, notably Murphy are designed to follow the sound modulation in order to maintain a more constant signal/noise ratio.

Noise limiter for sound channel of Murphy television set.



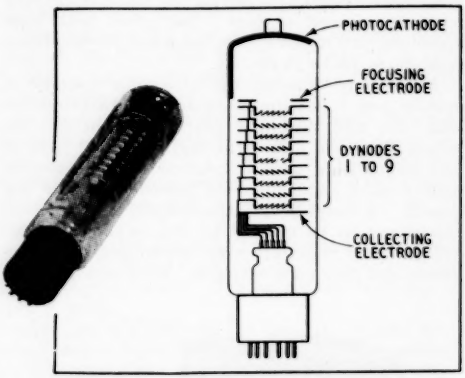
Hard-valve time bases, mostly working on the blocking-oscillator system, are slightly in the majority; but many examples of conventional gas-filled types exist. The Philips hard-valve generators are unusual in using triode-hexodes in a multivibrator circuit; and the Ferranti line time base in having only one valve, feeding a high-impedance deflector coil.

E.h.t. supply for the tube anode is still generally conventional, but there is a tendency towards obtaining it by rectifying the line fly-back (Kolster-Brandes and Philips) or separate r.f. oscillator Ekco and McCarthy), which confers the considerable advantage of safety to life.

In the Baird models, focusing is stabilized by passing the magnet current through a pentode. Several makes (Cossor, Kolster-Brandes) focus with a permanent magnet. Ion burn is prevented in the Cossor models by arranging for the beam produced by the gun to be off the axis of the c.r. tube. A small permanent magnet clipped each side of the tube between cathode and anode produces a relative deflection between electrons and ions enabling the latter to be excluded from the beam and the former to be brought on to the axis.

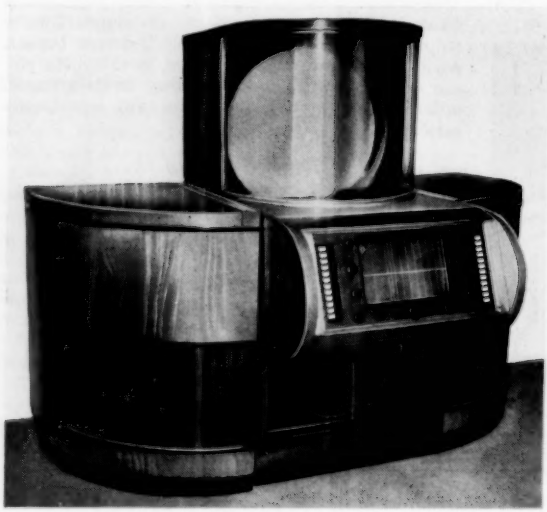
The Ekco TSC48 is exceptional in having an indirectly-viewed tube, using an inclined mirror. Only two examples of large screens were to be seen; these represented quite different approaches to the problem. The Baird "Grosvenor" televisor employs an enormous c.r. tube, with flat metal screen and offset gun as in a camera tube. The picture, 19in × 22in, is viewed from the beam side, so not only is curvature of the screen absent but it is exceptionally brilliant. Keystone distortion is prevented by frame modulation of line scanning, as in camera tubes. This televisor is combined with an 11-waveband receiver, auto-radio-gramophone, and sound recorder. The H.M.V. large-screen model is of the projection type, with a high-intensity c.r. tube picture enlarged by a Schmidt lens system.

The difficulties caused by "tilt and bend" in television camera tubes are appreciable even for studio work, where complete changes of light and shade distribution are infrequent and under control. But the task of compensation is much harder with film broadcasting, which hitherto has also depended on Emitron cameras. A new method developed by E.M.I. is a development of the spot-light principle, in which the object is scanned by a beam of light confined at each instant to one picture element, and the resulting light applied to a photo-cell. The difficult problem of sensitivity has been solved by a 9-stage electron-multiplier photo-cell, having an overall sensitivity of 10 amperes per lumen. The multiplier consists of the usual succession of electrodes held at progressively more positive voltages, and direct passage of primary electrons is prevented by the venetian-blind shape of the electrodes.



Electron multiplier used in the E.M.I. television film scanner.

Interlaced scanning is effected in an ingenious manner. A raster is set up on a 15-kV c.r. tube, its dimensions being approximately 3¼in × 1¼in; i.e., an aspect ratio of 10 : 4 instead of 5 : 4. A horizontally split lens focuses this raster on the continuously travelling film in two places, one of which is covered during a frame period by a revolving shutter. The frame motion of scanning, combined with the movement of the film in the opposite direction, spreads out the 10 : 4 raster into the 5 : 4 picture aspect ratio. When one frame has been scanned, the return of the beam



Baird Grosvenor television set giving a picture 22in by 19in.

to the start, combined with the movement of the shutter, brings the second raster into the correct position for interlacing the same frame on the film.

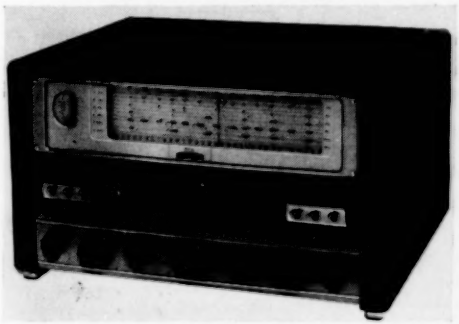
Non-Broadcasting Equipment

General-purpose communication receivers differ little in principle from pre-war types; but there are detail refinements, and improvements resulting from wartime techniques. The G.E.C. BRT400 is an example; a 13-valve superheterodyne with two r.f. stages and six wavebands from 150 kc/s to 31 Mc/s. Some of the valves are used in the a.g.c. system and in stabilizing and smoothing the power supply, which includes no electrolytic capacitors. A less elaborate model is the Eddystone 680, with two r.f., f.c., two i.f. (the first with crystal filter), combined detector, a.g.c. and a.f. amplifier, tetrode output, noise limiter, and beat oscillator. A signal strength meter is fitted.

The Standard Telephones STR9 aircraft transmitter-receiver is a good example of miniature construction (contrastingly exhibited alongside the final stage of a 135-kW short-wave broadcast transmitter), weighing only 22 lb. It has four interchangeable crystals to control spot frequencies in the band 115–145 Mc/s, and one fixed crystal produces the correct i.f. difference for stabilizing the receiver oscillator.

The Murphy-made portable Wireless Set No. 31 provides 40 v.h.f. f.m. speech channels for Army use. The same firm's radio telephone for small aircraft weighs 16.5 lb and has only one control—the on/off switch.

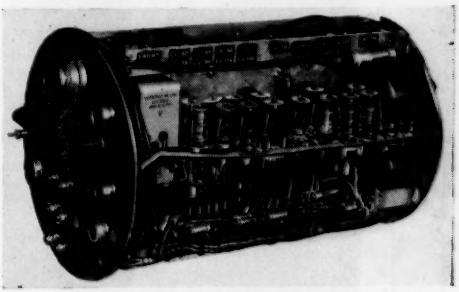
Marine radar installations, generally conforming to the Ministry of Transport specification, were shown by Marconi, E.M.I., Cossor, Metrovick and



G.E.C. Type BRT400 communications receiver.

B.T-H. These all operate in the 3-cm band and enable objects to be detected as close as 50 yards from the scanner. Presentation is by p.p.i., but the form differs considerably. The miniaturized Rebecca Mk IV, a radar interrogator used as a navigational aid, includes 48 valves and is contained in a pressurized cylindrical box 18in long by 10in diameter.

Dielectric and eddy-current heating are now accepted practice in many industrial processes, and the generators shown by several manufacturers



An example of miniature technique as applied to Rebecca Mk. IV.

incorporate many refinements, such as process timers, as standard fittings. An interesting application of induction heating in the radio industry itself was demonstrated on the E.M.I. stand. The process of sticking loudspeaker cones to their spiders had previously required a 20-minute pressing operation; in the induction heater 1½ seconds is sufficient, and the result is more reliable. The generator operates at 1 Mc/s, and is well screened and filtered to prevent interference. The same firm has a laboratory-type 4-kW dielectric heater at 15-45 Mc/s, provided with comprehensive metering and separate applicator; also 1- and 3-kW factory types. The Philips induction heater has an output of 50 kVA and a frequency range from 350 to 1,000 kc/s.

Miscellaneous industrial electronic applications included the Ferranti yarn-breakage detector, in which a wire stretched across the textile machine is attached at one end to a piezo-electric crystal. The slightest touch of a broken thread trips a relay which actuates an alarm or a knock-off device on the machine. Response to factory vibration is prevented by low-frequency attenuation of the crystal output. A photo-electric unit, for automatically adjusting the edge position of a moving belt of cloth or paper, is provided with an anti-hunting control which enables the damping of the movement to be critically adjusted. The same firm showed an experimental model of a hyperbolic computor, into which are fed the data received from a hyperbolic navigational aid such as Decca, Gee, or Loran. If the polar coordinates of the destination relative to the navigational ground master station are set up on the instrument's dials, it computes and continuously indicates the range and bearing of that destination from the ship or aircraft. A model now under development is expected to be accurate to 0.1 per cent in range and 0.3° in bearing.

E.M.I. eddy-current r.f. heater for the high-speed manufacture of loudspeakers.

A trigger unit for attachment to the well-known G.E.C. magnetic sorting bridge enables particles of ferrous metals to be detected in manufactured products. G.E.C. also showed a direct-reading moisture-percentage indicator for timber, depending on the resistance of the timber when a pointed electrode is pushed into the sample.

The Dynatron electronic counter is a scale-of-two instrument for Geiger-Muller work, counting up to 10^6 at a maximum speed of 300 pulses per second. The B.T-H. industrial process timer covers the range 0.6-120 seconds with an accuracy of ± 5 per cent; and the Metrovick timer provides for six stages in sequence, each 0.5-20 seconds. The switches, rated at 5A, 230V, are controlled by relays in the screen circuits of Blumlein-Miller integrator valves. Models are available for times up to several hours, and they are stabilized against mains voltage variations.

The Marconi Instruments TF884 plating thickness meter indicates directly the thickness of metal plate or paint, from 10^{-4} to 10^{-2} in, on a ferrous metal base, with an accuracy of ± 20 per cent. The probe, which is held against the surface to be tested, consists of a ball-ended centre pole in a transformer core having an annular air gap close to the ball. The primary winding is supplied with 50 c/s, and the secondary voltage, which depends on the influence of the plating thickness, is taken to a valve voltmeter.

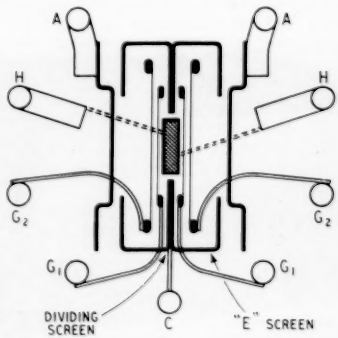
Valves and Cathode-Ray Tubes

It is too soon to discern what will be the ultimate effect of the introduction of the two new standard British bases, B8A and B8B. Ediswan and Mullard have already produced a range of types (with and without spigots respectively) on the B8A base, which is a miniature standard for all except the higher power types; and Tungsram have announced their intention to do so. The majority of miniature valves at present listed, however, have B7G bases, as in America.

Regardless of bases, the general tendency, stimulated by television and other v.h.f. requirements, is towards all-glass envelopes. Concurrently with this, top connections are abolished in r.f. pentodes and tetrodes, being now reserved for extra-high voltages and other exceptional requirements.

It is easier to introduce a new type or range of valves than to liquidate an old one; the result being that the number which have to be regarded as current builds up to what is now a highly uneconomic level. With this in view the Sargrove-Tungsram UA55 valve has been introduced. It consists of a double tetrode of very economical construction, unfortunately on yet another base, with nine pins. By varying the electrode connections and voltages it can be used for every purpose in a receiver, and even to provide characteristics—such as variable variable-mu—not obtainable with other types.

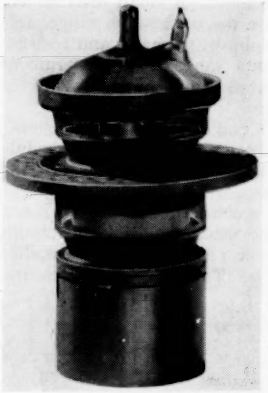
The Osram ACT22 and ACT23 are both earthed-grid triodes for use up to 1,000 Mc/s, and are key components in the future London-Birmingham television link. The former has a stage gain of 8, a dissipation of 75 watts, and an efficiency of 40 per cent at maximum frequency and 60 per cent at 600 Mc/s. The anode dissipation of the ACT23 is 250 watts. Both are used in coaxial tuning circuits, as in certain wartime radar transmitters.



Electrode arrangement and base connections of the Sargrove-Tungsram UA55 all-stage valve.

New types of power and control valves have been produced for industrial equipment. The well-known Mullard silica construction has been extended at both ends of the power range to include the TYS2–250 giving 500 watts output at 75 Mc/s, and the TYS5–3000, giving 10 kW at 30 Mc/s. Small electronic devices, such as photo-electric

relays, are at a disadvantage if cathode heating power has to be supplied continuously. More attention is therefore due to the Ferranti cold-cathode gas-filled valves—the K3 and K3A triodes and NSP1 and NSP1E tetrodes. The latter have been used hitherto mainly as stroboscopic light sources, but are useful in many relay applications.



Osram ACT23 u.h.f. triode giving 75 W output at 30 cm.

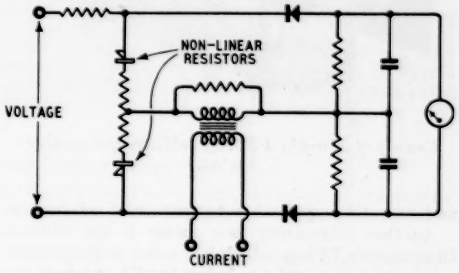
An unusual "valve" is the Mullard DDR100, which is an accelerometer double-diode. The anodes are elastically supported, so that the anode impedances of the two change differentially when accelerated mechanically. Arranged in a bridge circuit, the out-of-balance voltage produced is a linear function of the acceleration.

Cossor Type 89 cathode-ray tube with flat screen.

Flat-ended c.r. tubes are now being produced by Cossor (Type 89, 3½in) and G.E.C. (9in) for precision oscilloscopes and televisors respectively. Apart from these, and the giant Cinema-Television tube in the Baird "Grosvenor," c.r. tube developments are confined to internal details, to which intensive wartime research has contributed largely.

Instruments

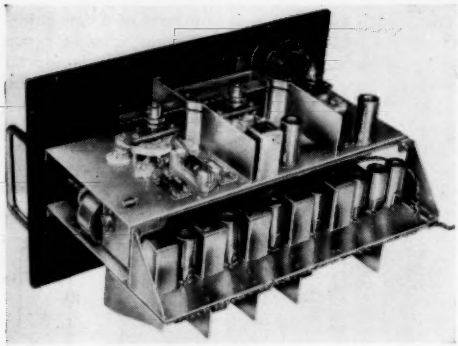
The B.T-H. silicon crystal rectifiers, developed primarily as centimetre-wave detectors, have greatly extended the frequency range for which direct-reading meters without power supplies are available. For example, a.c. voltmeters of apparently conventional type have been constructed for use up to 1,000 Mc/s, at 10,000 ohms per volt. B.T-H. germanium rectifiers have a smaller effective frequency range, but are capable of handling more power, and are convenient substitutes for diodes in all except high-impedance circuits. The range of "Westalite" rectifiers has been extended to include types of particular interest to electronic instrument designers, notably in the 16K series, which is a more compact (wire-ended) version of the 16HT type, and is obtainable for outputs of a few milliamperes with input voltages in multiples of 15 up to 135. Vacuum-mounted quartz crystals for all fundamental frequencies up to the v.h.f. band were shown by Standard Telephones and Marconi; and in addition to crystals, Salford Electrical Instruments now have a crystal-controlled frequency calibrator with its fundamental at 100 kc/s and useful harmonics up to 30 Mc/s, with provision for a.f. modulation.



Vampire low-consumption wattmeter (Everett Edgcumbe).

Very interesting possibilities are opened up by the Everett Edgcumbe "Vampire" multi-range volt-amp-power meter. The present model is for power frequencies, and embodies a wattmeter having a far lower consumption—of the order of 0.25 VA—than the conventional dynamometer type. It is an adaptation of the phase discriminator circuit. With no current in the current coil, the 2-phase input to the meter from the supply voltage is balanced and there is no reading. When current flows, the input to the meter is proportional to $I \cos \phi$. To make the readings proportional to $EI \cos \phi$, Westalite 16K rectifiers are used in the bridge; their non-linearity causes the current into the meter to rise with voltage. With the use of germanium rectifiers it is hoped to produce a low-consumption wattmeter suitable for high radio frequencies,

Marconi Instruments TF899 valve millivoltmeter covering 20—2,000 mV at frequencies up to 100 Mc/s.



Chassis of Murphy FSM23 field-strength measuring set.

and therefore applicable to industrial r.f. heaters.

Another interesting new meter is the Marconi Instruments TF899, which is a valve millivoltmeter using one active and one balancing EL91 triode in a bridge circuit, and is scaled from 20–2,000 mV in three ranges. Accuracy is given as ± 1 db to 50 Mc/s and ± 2 db to 100 Mc/s. It responds to peak voltages and is scaled in r.m.s. values with sine waveform.

The Murphy field-strength and noise meter, FMS23, is a sensitive superheterodyne receiver covering 30–150 Mc/s, calibrated directly in μV, and adjusted with reference to first-stage noise. Bandwidth is 100 kc/s at 6 db down.

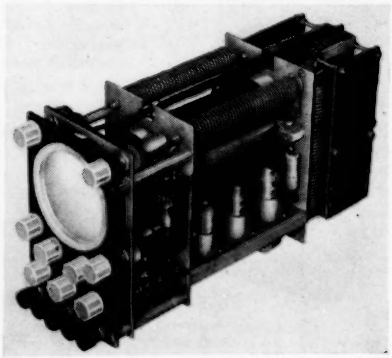
A Marconi Instruments policy is to introduce combination instruments where frequency of use justifies them. The TF888 portable receiver tester is an example. It includes signal generator, output power meter, and crystal calibrator; with mains or battery supply.

In the Dawe Instruments Modulated R.F. Oscillator, covering 10 kc/s to 50 Mc/s, the output is fed through an aperiodic buffer amplifier.

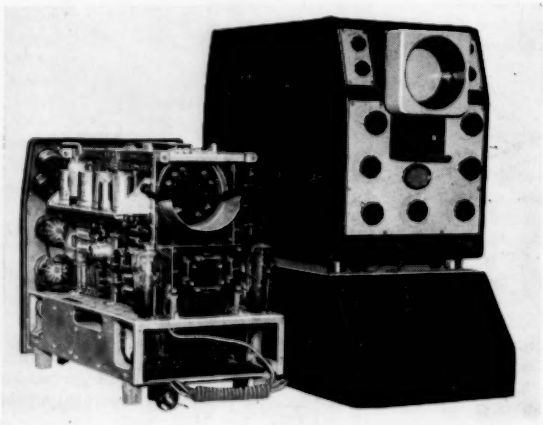
For television-receiver servicing, the Sobell TE. 123A generator supplies a complete synchronizing waveform, with a pattern of squares for checking time-base linearity.

The functions of insulation and continuity tester are conveniently combined in the Everett Edgcumbe portable "Hum Metrohm." A small internal dry battery acts directly on the 0.1-20-ohm range, and is stepped up to 500 volts by a buzzer and rectifier for the 0.05–25-megohm range. The instrument can be held and operated in one hand, leaving the other free for probing.

Oscilloscopes tend in two directions; the general-purpose instrument is becoming smaller, and the full-size instrument is becoming more precise and specialized. An example of the former is the Metrovick Type 244, which although only 10½in. × 5½in × 3½in has all the usual facilities, including a time base 20 c/s to 100 kc/s and a deflection amplifier effective up to 3.5 Mc/s. The latter are represented



Metropolitan Vickers miniature oscilloscope Type 244.



by two new Cossor models, the 1035 and 1049. Both use flat-screen double-beam tubes, and the controls are calibrated in time and voltage, while there are many special facilities. The first is for general laboratory use; the second more especially for industrial purposes.

There is now available for the Salford Miniscope an extra c.r. tube unit. This plugs into the top of the oscilloscope and derives its power supplies and time-base deflection voltage from it. It thus converts the oscilloscope into a two-tube instrument, in which the tubes have a common time base but which can display independent signals.

Cossor Model 1035 oscilloscope.

NEW BOOKS

Fundamentals of Radio

By JORDAN, NELSON, OSTERBROCK, PUMPHREY and SMEBY. Edited by W. L. EVERITT. Pp. 400 + xiii. Constable and Co. Ltd., 10, Orange Street, London, W.C.2. Price 27s. 6d.

It is a favourite technique with authors of the "Made Easy" type of book to ensure that at least the first page is within the capacity of the dimmest reader. It is presumed that his inertia, having been overcome by the encouraging discovery that he can actually understand what he reads, will keep him reading while the author gradually quickens the pace as much as he dare in order to cover the allotted subject-matter in the time allowed.

The authors of "Fundamentals of Radio" start almost at rock-bottom, with a simple outline of our system of digits; and the subject-matter (as the editor's preface says) is "the basic material of radio required for all types of radio work, both civil and military." To accomplish the feat in 400 pages it is obvious that there must be considerable acceleration, or considerable omissions, or both.

The editor does, in fact, keep his promise that "the reader need have only an elementary knowledge of algebra, which is reviewed briefly in Chapter 1," and he does cover a surprisingly wide field, including transmitters and receivers in some detail (f.m. as well as a.m.), sound reproducers, aerials, transmission lines, d.f., electromagnetic waves, and propagation. Some parts of television are briefly treated, but radar and waveguides are not mentioned.

The claim to have "covered each topic in such a way as to make clear the functioning of a complete radio system" might be questioned at a few points, but can broadly be conceded. That the authors "have also laid the foundation for a more advanced study of the subject," however, is a statement that seems to need some qualification. It is obvious all the way through that the authors have been very afraid of allowing unrelieved theory to go on for more than a page or two at a time. The editor even suggests omitting the first three chapters, on elementary algebra and d.c. and a.c. circuits, until "the need arises." This desire to keep the reader's feet on the ground by introducing applications as often and as early as possible is no doubt necessary and desirable for those whom he assumes will read the book. But to reach an engineering standard in radio it would be necessary to have rather more solid foundations of mathematics and electricity.

The trouble about explaining the first step very simply and fully is that the reader may expect his difficulties to be as well met throughout. If so, he is likely to be disappointed. Thus Ohm's Law, which is stated to be the basis of a "large portion of electrical circuit theory," is given as "The current in amperes is equal to the pressure in volts divided by the resistance in ohms," but as resistance has already been defined as the ratio of voltmeter reading to ammeter reading the importance of the Law is not clear, especially as the reader is warned not to worry when he finds it has many exceptions. What the writer is evidently trying to say is "In d.c. circuits the pressure in volts divided by the current in amperes (i.e., what is called the resistance, in ohms) is very often constant." This failure to bring out clearly the essential point is not uncommon. For example, decibels are explained twice; the first time on a subjective basis as "a unit of sound intensity" and "a unit of sound level," and loudness is taken as synonymous with power. The numerator in the power ratio must, it appears, always be larger than the denominator. Fortunately the second explanation (in the chapter on sound) indicates that sound is not necessarily involved wherever db are used.

The general scheme is well adapted for the instruction of intending servicemen and technical assistants, but the writing would benefit from some revision.

M. G. S.

Radio (3rd Edition)

By ELMER E. BURNS. Pp. 293 + xvi. Macmillan and Co., Ltd., St. Martins St., London, W.C.2. Price 15s.

This book is of American origin and was first published in 1928. The third edition appeared in 1938 and the copy under review is a seventh printing of this third edition. The book is thus admittedly nine years old, but a glance through it gives the impression that it is at least 20 years behind the times.

The first chapter contains circuits and pictorial wiring diagrams of crystal sets, valve amplifiers and complete receivers. The five-tube receiver of Figs. 18 and 19 is an historical gem. There are two r.f. stages with three tuned transformer couplings, a grid detector, and two transformer-coupled a.f. stages. All the valves are triodes and each one is provided with a separate filament rheostat! The r.f. stages are not neutralized and no valve has grid bias beyond the volt or so provided by the drop across the rheostats!

This is seriously put forward as a set for the beginner to experiment with. It is not even representative of 1928 practice, for the reviewer well remembers using neutralized circuits at least two years earlier, and in 1928 the screen-grid valve was coming into general use after its appearance in the autumn of 1927.

The screen-grid valve is not completely forgotten, however, for it is given 50 lines of description and there is one circuit of a straight receiver embodying it and one of a superheterodyne. Beam tetrodes and such matters as Class A, B, AB and C amplifiers are mentioned, but only just, and it is obvious that they have been added in a "revision" to make the book appear up-to-date.

The book is mainly devoted to fundamental theory of an elementary kind and the author would no doubt say that this does not change with time. In this he would be right, but when the theory is riddled with references to out-of-date practice, it removes any excuse for having failed to revise the practise. There are many statements in the theoretical part which are now incorrect, although they may have been right when they were written; e.g., "The output of a detector tube under proper operating conditions is nearly proportional to the square of the input voltage." Proper conditions

for most purposes today are those which make it directly proportional to the input.

There are many characteristic curves of triode valves which are used to illustrate their operation. Fig. 226 shows cut-off at about -3 V grid potential but is carried on to $+24$ V and in Fig. 126, which shows cut off at -9 V, the curve is carried up to $+16{\cdot}5$ V and exhibits distinct signs of saturation.

The reviewer failed to find a single characteristic curve of a tetrode or pentode. The index gives two references to the pentode, one is precisely a page in length, the other is two lines. The superheterodyne has some $2\frac{1}{2}$ pages.

Further extracts or comment would be superfluous. W. T. C.

The Principles and Practice of Wave Guides

By L. G. H. HUXLEY, M.A., D.Phil. Pp. 328 + xi, with 148 illustrations, Cambridge University Press, Bentley House, 200, Euston Road, London, N.W.1. Price 21s.

This is the first book of a new Cambridge series on "Modern Radio Technique" under the general editorship of J. A. Ratcliffe. Its aim is to provide an introduction to the great practical developments in the use of waveguides which have taken place during the war years, and it is based on courses given by the author at the Radar School of the Telecommunications Research Establishment.

The first chapter is a short introduction to general properties of the electromagnetic field. The second and third chapters deal with the propagation of waves in rectangular and circular guides. The existence and elementary properties of the E- and H-waves in a rectangular guide are deduced by synthesis of their plane-wave components with the aid of only simple mathematics. The reasoning is easy to follow and is aided by excellent diagrams, leaving the reader with a clear physical understanding of these waves. The many well-drawn diagrams are a feature throughout the book. Incidentally a statement near the beginning should be of assistance in emphasizing what is present practice, "The TE and TM nomenclature is American and the E and H nomenclature is British." The latter form is therefore used in this book.

For the higher wave types and for the circular waveguide the synthetic method does not go far, and here the various formulae are simply quoted without proof.

The fourth chapter gives details of the use of bends, couplings, etc., and of some associated microwave apparatus. Again the drawings are to be commended. It is to be doubted whether readers will appreciate the point of the choke coupling from the description. The principle of transference of poor contact from a low-impedance to a high-impedance point is not mentioned.

Chapter 5 occupies one-third of the book and is concerned firstly with impedance in waveguides, then with the effect of obstacles, irises, junctions, etc. in terms of impedance. Next propagation in corrugated waveguides, a recent and important aspect, is considered, and finally the important research work on slot couplings and radiating slots is briefly dealt with. The treatment of impedance based on standing-wave ratios is good, but trouble arises when on p. 119 total impedance is defined in terms of intrinsic impedance, with a reference to a later section §7.16. Some search locates this reference in §7.17, where one finds (p. 303) that the sides a, b of a guide become interchanged in the argument, resulting in the factor b/a becoming inverted in the formula for total impedance. Then on p. 196 the formula for total impedance (correct this time) is rightly used in connection with impedance matching, but this is continually referred to as intrinsic impedance and the symbol for intrinsic impedance is used in the formula. On p. 137 in the formula for the admittance of an inductive iris the factor λ_g/W is omitted, but the reader has no means of detecting this error since the formula is quoted without proof.

The next chapter on cavity resonators and their applications is clear, but suffers from the simplified treatment which leads the author to state that the lowest E-mode in a rectangular resonator is the E_{111}, whereas in fact it is the E_{110}. Again the E_{011}-type appears as the lowest E-mode in the cylindrical resonator, instead of the E_{010}. The latter is an important wave type in this resonator, but appears only casually some pages later.

The final chapter, in the form of appendices, is strictly mathematical, being intended as a more formal approach to the subject, and in it most of the results previously quoted are proved. The author has adopted the best approach through the Hertzian vectors, and the treatment for the various solutions of the wave equation is quite standard. Once again, however, resonators prove a stumbling block, for the characteristic values given for the spherical cavity contain errors: on p. 275 the value 5.8 quoted for ρ_{11} is actually that for ρ_{21}, and should be 4.49. The value for ρ_{12} should be 7.64, not 7.72. The chapter continues with short treatments of diverse subjects of which the most interesting are Babinet's principle and Lorentz's reciprocal theorem.

The physical approach, using only simple mathematics, is maintained up to the last chapter and the result is very clear, but the reviewer feels that the relevant parts of the rigid treatment would have had a much better chance of being read and understood had they been mixed in throughout the book. It is a pity that so many errors should have been allowed to mar an otherwise excellent book. Unfortunately the simplified approach, which uses so much material proved only in the last chapter, makes it difficult for the reader to detect these errors.

The material is quite up-to-date; in fact much of the work has hitherto been contained in secret reports, which are only now appearing in various journals.

The author's position during the war has kept him in close touch with both the theoretical and the experimental sides, so that the book is essentially practical—one can hardly blame it for being a little biased towards T.R.E. practice. A pleasing feature is the number of calculations involving actual experimental results.

The printing and binding are good, and this, with the other books of the series, should form a handsome addition to British technical literature.

H.R.L.L.

Guide to Broadcasting Stations (3rd Edition)

Pp. 64. Compiled by *Wireless World*, Iliffe & Sons, Ltd., Dorset House, Stamford St., London, S.E.1. Price 1s. (postage 1d.).

WIRELESS PATENTS

A Summary of Recently Accepted Specifications

The following abstracts are prepared, with the permission of the Controller of H.M. Stationery Office, from Specifications obtainable at the Patent Office, 25, Southampton Buildings, London, W.C.2, price 1/- each.

DIRECTIONAL AND NAVIGATIONAL SYSTEMS

584 496.—Radiolocation system of the frequency-modulated type in which distance is indicated by the relative amplitude of the sidebands grouped around two selected harmonic frequencies.

Sperry Gyroscope Co. Inc. (Assignees of R. H. Varian). Convention date (U.S.A.) 10th April, 1943.

584 573.—Cathode-ray direction-finder in which the radius of the circular time-base is momentarily increased near the critical phase-position.

Svenska Akt. Gas Accumulator. Convention date (Sweden) 4th January, 1944.

584 606.—Relaxation circuit for generating marking-pulses and scanning-waves for measuring time-intervals on a c.r. indicator, say in radiolocation.

Standard Telephones and Cables Ltd. (Communicated by International Standard Electric Corpn.) Application date 24th November, 1943.

584 670.—Radio-navigational system in which the pulses radiated from a fixed transmitter are automatically modulated by the corresponding echo-signals from an aeroplane in such a way as to indicate to the pilot whether or not he is keeping to a predetermined course.

A. H. Reeves and F. C. Williams. Application date 1st October, 1943.

584 727.—Radio-navigational system in which two or more spaced transmitters radiate waves which produce a radiation-pattern to allow the pilot of a moving craft to identify his position in terms of their relative phasing.

H. F. Schwarz, W. J. O'Brien, and Decca Radio and Television Ltd. Application date 4th June, 1941.

584 786.—Radiolocation system in which the exploring pulses from a central transmitter are time-modulated to convey signals indicative of the bearing and distance of a target to outlying stations.

Standard Telephones and Cables Ltd. and W. A. Beatty. Application date 29th December, 1939.

584 848.—Skiatron type of c.r. tube arranged for the large-scale reproduction of positional data derived, say, from radiolocation equipment.

R. A. R. Tricker, A. Tutchings, J. C. C. Stewart and C. S. Wright. Application date 14th April, 1943.

585 057.—Deriving a monitoring-signal, and preventing undesirable interaction, in a d.f. system in which N.S. and E.W. signals are fed through separate amplifiers to a cathode-ray indicator.

Amalgamated Wireless (Australasia) Ltd. Convention date (Australia) 10th July, 1943.

585 207.—Radiolocation equipment in which a klystron oscillator is operated at one natural frequency for the transmitted pulses, and at another natural frequency for heterodyning the echo-signals.

J. Sayers, M. L. E. Oliphant and C. S. Wright. Application date 5th March, 1941.

585 347.—Radiolocation system of interrogation and response for establishing the identity of unknown mobile craft in which the required information is masked from unauthorized listeners.

F. C. Williams. Application date 13th March, 1943.

585 353.—Super-regenerative receiver, particularly for the i.f.f. system in a radiolocation set, in which the "prevailing-noise" voltage is utilized to control stability (divided from No. 585 347).

F. C. Williams. Application date 13th March, 1943.

585 393.—Course-indicating system of the overlapping-beam type designed to provide maximum discrimination between the "on-course" and "off-course" signals.

Marconi's W.T. Co. Ltd. and E. Green. Application date 27th January, 1944.

585 473.—Radiolocation device of the variable-frequency type in which a grounded-grid triode is used to develop the required beat frequency between outgoing and reflected signals.

Standard Telephones and Cables Ltd. and E. O. Willoughby. Application date 1st August, 1944.

585 656.—Blind-landing system, in which the aircraft is steered by the beacon signals when "off-course," and by a magnetic compass or gyroscope when "on-course."

N. F. S. Hecht and G. W. H. Gardner (Secret Patent first published 29th January 1947). Application date 24th May, 1938.

RECEIVING CIRCUITS AND APPARATUS

(See also under Television)

585 365.—Method of stabilizing the frequency of a tunable circuit comprising capacitances, reactances, and inductances in shunt.

A. C. Lynch. Application date 10th July 1944.

585 588.—Frequency-discriminating circuit, including a valve with a reverse feedback reactance, for receiving frequency-modulated signals.

Marconi's W. T. Co. Ltd. (assignees of M. G. Crosby). Convention date (U.S.A.) 27th April, 1943.

585 613.—Super-regenerative circuit for selecting a desired train of signal-pulses from other pulses, and from fortuitous disturbances.

Standard Telephones and Cables Ltd. and C. W. Earp. Application date 15th September, 1944.

585 624.—Receiver with an input circuit designed to allow conveniently the alternative use of a rotatable frame-aerial or an outside aerial.

A. F. Burgess (communicated by Zenith Radio Corpn.). Application date 24th October, 1944.

585 723.—Receiver in which the tuning is periodically swept over a wide frequency-range to give a cathode-ray indication of the presence of all signals within that range.

Auto-Ordnance Corpn. Convention date (U.S.A.) 20th July, 1943.

TELEVISION CIRCUITS AND APPARATUS

For Transmission and Reception

584 494.—Rotary-disc or shutter device for protecting the fluorescent screen of a television tube from extraneous light.

The General Electric Co. Ltd., and L. C. Jesty. Application date 28th February, 1944.

584 916.—Reducing "flicker" in a television receiver where light from a separate source is projected through a sensitive fluid-film, which is scanned by an electron stream.

Ges. Zur Forderung Der Forschung &c., Technischen Hoch Schule. Convention date (Switzerland) 25th January, 1943.

584 969.—Arrangement of the focusing and deflecting electrodes in a television tube of the mosaic-screen type.

Western Electric Co. Inc. Convention date (U.S.A.) 30th January, 1943.

584 970.—Construction and method of scanning the mosaic screen of a television transmitting tube.

Western Electric Co. Inc. Convention date (U.S.A.) 30th January, 1943.

584 997.—Television system in which the signals generated on one mosaic screen are fed to a second screen, where they are reversely scanned, in order to offset the so-called "tilt" effect.

H. G. Lubszynski. Application date 16th March, 1944.

SIGNALLING SYSTEMS OF DISTINCTIVE TYPE

585 263.—Multiplex signalling system in which a number of interleaved pulse-trains are produced by keying a frequency-modulated carrier-wave.

Standard Telephones and Cables Ltd. (assignees of L. Dubin). Convention date (U.S.A.) 12th February, 1944.

585 688.—Frequency-selective arrangement, comprising two resonant circuits of equal tuning, but different magnification factors, the output from each being combined in opposition, for multi-channel signalling.

B. M. Hadfield. Application dates 22nd May and 28th October, 1944.

CONSTRUCTION OF ELECTRONIC-DISCHARGE DEVICES

584 334.—Cathode-ray tube with two or more target electrodes for use in phase or frequency modulation.

The Telephone Manufacturing Co. Ltd. and W. Saraga. Application date 20th September, 1944.

584 787.—Construction lending itself to the mass-production of ultra-high-frequency oscillators of the resonant cavity type.

The British Thomson-Houston Co. Ltd. Convention date (U.S.A.) 28th March, 1942.

584 944.—Velocity-modulation tube in which a magnetized ring is arranged to be rotated in order to align the electron stream with respect to an aperture in the hollow resonator.

Ferranti Ltd., W. R. J. Mayes and E. J. Whitmore. Application date 26th June, 1944.

585 208.—Construction of high-powered klystron oscillator in which the hollow resonators are formed in a block-anode and the electron-stream is confined to a relatively-thin lamina.

J. Sayers, M. L. E. Oliphant and C. S. Wright. Application date 5th March, 1941.

585 447.—Construction of high-frequency triode in which the control-grid is formed with an external disc which acts as a screen between resonant transmission-line input and output circuits.

Standard Telephones and Cables Ltd. and S. G. Tomlin. Application date 10th May, 1941.

585 448.—Construction of high-frequency amplifier wherein the anode and cathode are contained in separate envelopes, associated with a metallic disc to which the grid is connected.

Standard Telephones and Cables Ltd. and J. Foster. Application date 13th June, 1941.

585 449.—Construction of a high-frequency amplifier in which an external screening-disc is sealed-in, through the glass envelope, into contact with the grid.

Standard Telephones and Cables Ltd., F. D. Goodchild and W. H. Wolsey. Application date 24th October 1941.

SUBSIDIARY APPARATUS AND MATERIALS

584 810.—Means for minimizing eddy-currents in a magnetic induction chamber for accelerating the speed of electrons over a circular orbit.

The British Thomson-Houston Co. Ltd. Convention date (U.S.A.) 10th September, 1943.

585 066.—Adjustable transmission-line element designed to give maximum electrical length for a given geometrical length.

Hazeltine Corporation (assignees of H. A. Wheeler). Convention date (U.S.A.) 28th January, 1944.

585 151.—Hand appliance, comprising a hollow resonator and adjustable plunger, for measuring wavelengths of the order of centimetres.

The General Electric Co. Ltd., W. A. Bourne and R. W. Sloane. Application date 13th October, 1943.

585 419.—Phase-shifting device for stabilizing the operation of a relay comprising a galvanometer, a gas-filled amplifier and a photo-electric cell.

D. C. Gall. Application date 4th August, 1944.

585 478.—Electronic switching circuit, reponsive to a train of pulses, and adapted to count or give an indication of the frequency of the switching wave.

Standard Telephones and Cables Ltd. and J. D. Weston. Application date 1st September, 1944.